Saunders' Question Compends

Essentials of Physiology

Sidney P. Budgett, M.D.

The New Standard

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SAUNDERS' QUESTION-COMPENDS. No. 1.

ESSENTIALS

OF

PHYSIOLOGY

PREPARED ESPECIALLY FOR

STUDENTS OF MEDICINE

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Second Edition, Thoroughly Revised

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ARRANGED WITH QUESTIONS FOLLOWING EACH CHAPTER

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PREFACE TO THE SECOND EDITION.

THE present revision has given opportunity to add a short summary of the adaptations of the blood in health and disease to foreign substances introduced into the body. A somewhat fuller treatment of the subject of human lactation and of the functions of the red and white blood-cells and of the blood as a tissue has seemed advisable. No change in the scope of the book has been attempted.

HAVEN EMERSON.

NEW YORK, *August, 1905.*

PREFACE.

THESE abbreviated lecture notes are intended for the use of students in conjunction with a text-book, and not as a substitute for a larger work. Consequently, no attempt has been made fully to illustrate this book. The questions introduced at the end of each chapter are not exhaustive, but may, it is hoped, if carefully considered, be found useful as an aid to thinking over what has been read.

CONTENTS.

PHYSIOLOGY.

CHAPTER I.

PROTOPLASM, BLOOD, AND LYMPH.

PROTOPLASM.

PHYSIOLOGY is the science of the functions of living matter, as distinguished from the science of the form of living matter, or Morphology. The two groups of living matter are plants and animals, which are distinguished physiologically by the following essential difference:

The plant is able by the aid of solar energy to construct its protoplasm from inorganic matter, *i. e.*, water, carbon dioxid, and inorganic salts. The animal cell is unable to form proteid material from inorganic material. The animal cell has feeble powers of synthesis and is characterized chiefly by its power to break down organic material into simpler compounds. The animal cell must make its protoplasm largely of organic compounds already formed.

Living **protoplasm,** or bioplasm, is composed of a fine network of fibrillæ in which the more fluid portion of the protoplasm is contained. Protoplasm is impossible of exact analysis since its life is destroyed by treatment with chemical reagents. It contains a large

store of potential energy; it is unstable; and has the following properties: **irritability, contractility, conductivity, nutrition,** or **assimilation,** including processes of construction and destruction, and **reproduction.**

By **irritability** is meant that property of protoplasm by virtue of which it is able to respond to a stimulus, which may be the normal nerve-impulse—probably consisting in the transmission of a physical rather than a chemical change along a nerve fiber—or an artificial stimulus, mechanical, thermal, chemical, or electrical. The response consists of a chemical change in the protoplasm, accompanied by the production of heat or visible motion or both, and often to a degree far in excess of the energy applied as a stimulus.

Contractility is the property by virtue of which protoplasm is able to change its shape; the simplest instance being the ameboid movement of the white blood-cells.

Conductivity is the property by virtue of which protoplasm is able to transmit an impulse from one part to another of its substance, as instanced in the passage of a nerve impulse.

By **nutrition** we mean the power of converting dead food material into living substance.

By **reproduction** we mean the power of each cell, or organism, to perpetuate its kind by the formation of new individuals.

The tissues of the human body consist of cells and intercellular substance, the latter being of simpler material than the protoplasm of the cells, manufactured by the cells, and lacking the characteristics of living matter.

On analysis, dead protoplasm is found to consist of water, inorganic salts, proteids, nucleoproteids, carbohy-

drates, fats, lecithin, cholesterin, and various simpler substances. Whether, and to what extent, these are, in the living condition, chemically combined with one another is not known.

Proteids are highly complex bodies of unknown composition, made up of carbon, oxygen, hydrogen, nitrogen, sulphur, and sometimes phosphorus, in the following proportions by weight: Carbon, 51 to 55%; Oxygen, 20 to 24%; Nitrogen, 15 to 17%; Hydrogen, 6.8 to 7.3%; and Sulphur, 0.3 to 5%. A single proteid molecule may perhaps contain as many as 2000 atoms; the molecular weight of egg-albumen being possibly as high as 14,000. Native proteids are coagulated by boiling; they are precipitated by alcohol, by the salts of the heavy metals, and by mineral acids, and are coagulated by prolonged treatment with alcohol; they are nondialyzable. The table on the following page gives the solubility of several native proteids, proteoses, and peptones.

Nucleoproteids are the most abundant proteids found in the cell protoplasm. They are compounds of a proteid and nuclein, nuclein itself being a compound of a proteid and nucleic acid, while nucleic acid may be split into phosphoric acid and nucleic bases, such as adenin, guanin, etc.

Carbohydrates are composed of carbon, hydrogen, and oxygen, the two latter being present in the proportions to form water; they are simpler than the proteids, though some of the polysaccharids appear to be very complicated in structure:

The carbohydrates may be divided into three groups, as follows:

Monosaccharids, *e. g.*, Grape-sugar, $C_6H_{12}O_6$.
Disaccharids, *e. g.*, Cane-sugar, $C_{12}H_{22}O_{11}$.
Polysaccharids, *e. g.*, Starch, $(C_6H_{10}O_5)_n$.

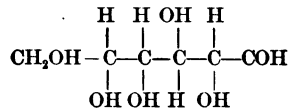
TABLE 1.

	Solubility.						
	Water.	NaCl Solution.				$(NH_4)_2SO_4$.	When Boiled.
		Dilute.	Half Saturated.	Saturated.	Saturated + acid.	Saturated Sol.	
Native Proteids:							
Albumin	Sol.	Sol.	Sol.	Sol.	Insol.	Insol.	Insol.
S. Globulin	Insol.	Sol.	Sol.	Insol.	Insol.	Insol.	Insol.
Fibrinogen	Insol.	Sol.	Insol.	Insol.	Insol.	Insol.	Insol.
Proteoses:							
Protoproteose	Sol.	Sol.	Sol.	Slightly sol.	Insol.	Insol.	Sol.
Heteroproteose	Insol.	Sol.	Sol.	Insol.	Insol.	Insol.	Sol.
Deuteroproteose	Sol.	Sol.	Sol.	Sol.	Slightly sol.	Insol.[1]	Sol.
Peptones	Sol.	Sol.	Sol.	Sol.	Sol.	Sol.	Sol.

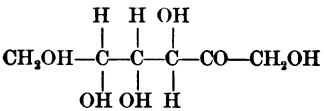
[1] The deutero-albumose formed on peptic digestion of proto-albumose is slightly soluble in a saturated solution of ammonium sulphate.

The stereochemical formulæ of many sugars are known, Emil Fischer having, in the laboratory, synthesized a greater number than are known to exist in nature. The **monosaccharids** are aldehyds or ketones of hexatomic alcohols, and are known as aldoses and ketoses; for instance, dextrose is the aldehyd of the alcohol sorbite; levulose, or fruit-sugar, is the ketone of the alcohol mannite.

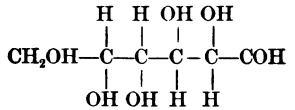
The stereochemical formula for Grape-sugar (d-Glucose, or Dextrose) is as follows:



For Fruit-sugar (d-Levulose):



In the formula for dextrose, it will be noticed that there are a number of possible different arrangements of the four intermediate CH.OH groups; for instance, we may transpose the H and the OH in the last group, thus:



and we have d-Mannose, another sugar of the aldose group. It would be possible for sixteen different aldoses to exist, each with the formula $CH_2OH.(CHOH)_4$-COH; of these, twelve are known. Like other alde-

hyds, they act as reducing agents, upon which property depend Trommer's and Fehling's tests.

A series of these glycoses has been investigated, beginning with Triose; in the triose group there are two possible isomers, only one, Glycerose, being known. The series is as follows:

Trioses,	$C_3H_6O_3$.	2	possible isomers.
Tetroses,	$C_4H_8O_4$.	4	" "
Pentoses,	$C_5H_{10}O_5$.	8	" "
Hexoses,	$C_6H_{12}O_6$.	16	" "
Heptoses,	$C_7H_{14}O_7$.	32	" "
Octoses,	$C_8H_{16}O_8$.	64	" "
Nonoses,	$C_9H_{18}O_9$.	128	" "

Only those containing three carbon atoms, or a multiple of three,—namely, members of the triose, hexose, and nonose groups,—are assimilable to more than a trifling extent; the others, when absorbed from the alimentary canal, being excreted unchanged by the kidneys.

Of the **disaccharids,** the three following are of interest: Cane-sugar, Malt-sugar, and Milk-sugar. Cane-sugar can, by hydrolysis (see below), be converted into one molecule of dextrose and one molecule of levulose; Malt-sugar, or Maltose, into two molecules of dextrose; and Milk-sugar, or Lactose, into one molecule of dextrose, and one molecule of galactose, another member of the hexose group.

Of the **polysaccharids,** starch, the dextrins, glycogen, and cellulose are familiar instances; the formula for each being $(C_6H_{10}O_5)_n$.

Fats are the ethereal salts of glycerin and fatty acids; animal fats usually being mixtures of the three fats:

Palmitin,	$C_3H_5(C_{16}H_{31}O_2)_3$.	Melting-point,	45° C.
Stearin,	$C_3H_5(C_{18}H_{35}O_2)_3$.	" "	53°–66° C.
Olein,	$C_3H_5(C_{18}H_{33}O_2)_3$.	" "	—5° C.

The melting-point of a mixed fat depends on the relative proportions of the mixture. Human fat contains from 67% to 80% olein, and is liquid at body-temperature.

Lecithin is a complicated nitrogen- and phosphorus-containing fat, found in all cells, and more especially in the nervous system.

Cholesterin, $C_{27}H_{45}OH$, is also found in the nervous system; it is a constituent of all cells, especially blood-cells, and is present in the bile. It is a monatomic alcohol.

Of special importance, amongst the inorganic salts of protoplasm, are the phosphates and chlorids of potassium, sodium, and calcium. Iron is also present, and is an indispensable constituent of the red blood-cell.

The sum of the chemical exchanges occurring in living tissue is known as **Metabolism.** The process of building up living tissues, or assimilation, may be spoken of as **Anabolism** and is constructive or synthetic. Destructive or analytic processes are summed up in the term **Katabolism.** There is never complete cessation of these processes even during rest of tissues or cells. Equilibrium is only obtained by constant change; the constant destruction which goes on within the cell demands an equally continuous supply of new material, which in the case of the proteids must be supplied as such from without. Hence the name **proteids,** or material "of first importance."

Since oxidation is one of the chemical changes in-

cluded under metabolism, a continuous supply of oxygen is another necessity. One of the chief products of oxidation is carbon dioxid; this, and other waste products arising from katabolic changes, must be removed from the cell as fast as they are formed, as their accumulation is injurious to the bioplasm, and destructive of its irritability.

Another characteristic katabolic change is *Hydrolysis*, which consists in the hydration and splitting-up of a comparatively complex substance into two or more simpler bodies; for instance:

$$\underset{\text{Glycogen}}{(C_6H_{10}O_5)_n} + \underset{\text{Water}}{nH_2O} = \underset{\text{Dextrose}}{nC_6H_{12}O_6}.$$

Amongst the anabolic or synthetic changes there occurs the opposite of hydrolysis—namely, one consisting of the building of two or more comparatively simple bodies into one complex substance, accompanied by dehydration; for instance:

$$\underset{\text{Dextrose}}{nC_6H_{12}O_6} = \underset{\text{Glycogen}}{(C_6H_{10}O_5)_n} + \underset{\text{Water.}}{nH_2O}$$

This is called *dehydrolysis.*

After the food has been absorbed by the walls of the alimentary canal, it is still far out of the reach of the majority of the cells of the body; the same is true of the oxygen that is absorbed from the air spaces of the lungs; the cells would thus starve to death but for the intervention of the Blood, which, as it passes through the vessels of the alimentary canal, takes up the food, and on its way through the pulmonary vessels, takes up oxygen, carrying these to all parts of the body. The blood is, however, inclosed in a system of tubes, so that only those cells which line the vessels can obtain their nourishment directly from the blood.

Through the walls of the smaller vessels, there filters out a liquid, closely resembling the blood plasma, called Lymph. In it, held in solution, are the necessary food-stuffs, and into it as it lies in the lymph-spaces, which intervene between the cells of the various tissues, there diffuses, from the blood-vessels, oxygen; so that the cells are thus supplied with both food and oxygen, through the lymph, by the blood. At the same time the waste products of cell metabolism pass from the cells into the lymph, and thus to the blood, by which they are carried to the various organs whose function it is to excrete them. The blood thus plays the part of both purveyor and scavenger. It also serves to equalize the temperature of the different parts of the body.

THE BLOOD.

The blood consists of cells and plasma. In that of man, the cells form about 48 % ; in that of women and children, rather less. The cells are of two varieties—the red cells, or erythrocytes; and the white cells, or leukocytes. Of the latter, there are several different forms. In the blood of man there are about 5,000,000 red cells to the cubic millimeter; in woman's blood, about 4,500,000. The number of white cells is very variable; on the average, there are about 10,000 to the cubic millimeter. In addition to the red and white cells, there are smaller bodies, called *platelets*, or *plaques;* about these very little is known; they are more numerous than the white cells, less so than the red; they disintegrate rapidly in blood that is shed.

The functions of the blood are as follows:

1. It carries to the tissues food-stuffs, after they have been properly prepared by the digestive organs.

2. It transports to the tissues oxygen absorbed from the air by the lungs.

3. It carries from the tissues various waste products formed in the processes of disassimilation.

4. It is the medium for the transmission of the internal secretions of certain glands.

5. It aids in equalizing the temperature and water-contents of the body.

6. It forms substances which neutralize, antagonize, or destroy foreign substances which may be introduced into the organism (see pp. 33 and 34).

The functions of the red blood-cells are:

1. To carry oxygen from the lungs to the tissues.

2. To carry carbon dioxid from the tissues to the lungs.

Composition of the Blood Plasma.—

Water	90%
Inorganic Salts ($NaCl$, Na_2CO_3, $NaHCO_3$, Na_2HPO_4, NaH_2PO_4, KCl, K_2SO_4, $Ca_3(PO_4)_2$, $CaCl_2$, etc.)	0.8%
Dextrose	0.12–0.2%
Fats	0.2–(1.0)%
Proteids:	
Serum-albumin	4.52%
Globulins: Serum-globulin	3.10%
Fibrinogen	0.50%
Urea	0.02%
Kreatin, uric acid, xanthin bases, lecithin, etc.,	traces.
Nucleoproteids (?).	
Ferments (diastatic, glycolytic, and steatolytic).	

It will be seen that the plasma contains all the necessary food-stuffs, proteid, carbohydrate, and fat. Water and the inorganic salts are of equal importance. The urea, kreatin, uric acid, etc., represent waste products of proteid metabolism.

It is absolutely necessary that the blood be alkaline. This is insured by the presence of the carbonates of

sodium, and in case of acid-poisoning, by the splitting off of ammonia from the proteid molecules.

The nucleoproteid found in the liquid part of the blood after it is shed perhaps originates from the leukocytes after the blood leaves the vessels, and may not be a normal constituent of the plasma. Ferments are present in small quantities only; a *diastatic ferment* is one which converts starch into sugar; a *glycolytic ferment* splits up sugar; a *steatolytic ferment* splits up fats.

The three proteids of blood plasma differ in their solubility, as is set forth in Table I. They also differ in the temperature at which they coagulate. Serum-albumin coagulates at three different temperatures: the first portion at 72° to 75° C.; the second at 77° to 78° C.; and the third at 83° to 86° C. Serum-globulin coagulates at 75° C.; Fibrinogen, at 56° C.; and Nucleoproteid, at 65° C.

Coagulation.—A highly important characteristic of blood is its power of clotting when shed; were it not for this, fatal hemorrhage might result from a very trifling wound. In the class of patients known as "bleeders" this is the case; their blood is lacking in the power of clotting. The term *hemophilia* is applied to this condition.

From three to six minutes after human blood leaves the blood-vessel, if conditions be favorable, it becomes syrupy in consistence, and later forms a jelly which contracts and expresses a clear yellow liquid—the **Serum.** This change depends upon the appearance, in the plasma, of innumerable fine fibrils, which are distributed throughout the whole mass of blood in the form of a close meshwork. In the interstices of this the blood-cells are entangled, so that they form a part of the clot, though not an indispensable part, for plasma may be caused to clot

after the complete removal of the cells, in which case the clot is a light yellow, transparent jelly.

The fibrils, on the formation of which clotting depends, consist of an almost insoluble proteid which is called **Fibrin.** If the blood, as it is shed, be collected in a vessel and whipped with a bundle of twigs, the fibrin fibrils adhere, as fast as they are formed, to the whipper, and may thus be removed from the blood. The blood thus **defibrinated** remains liquid indefinitely, and, by its appearance, cannot be distinguished from normal blood. If the fibrin collected in this way be washed free from the few blood-cells which are held between its fibrils, it is found to be a stringy, elastic substance, and gray in color.

In composition, serum is similar to plasma, save that it contains no fibrinogen; in addition, it contains a ferment of which mention will be made below. We see, then, that fibrinogen disappears during the clotting of blood. Further, if fibrinogen be removed before the blood has had time to clot, clotting will be entirely prevented; thus fibrinogen is necessary to the clotting of blood.

The **clotting of blood** depends upon the conversion of fibrinogen into fibrin. The next question is, What is the cause of this conversion? The clotting of blood may be prevented by the addition of a certain quantity of a salt, such as magnesium sulphate, the amount added being insufficient to precipitate the proteids of the plasma. Blood so treated is known as *salted blood*, and from it, by allowing the blood-cells to settle, can be obtained salted plasma, which remains liquid. Now, if to salted plasma there be added a small quantity of blood-serum, or a small quantity of an extract made from a blood clot, the salted plasma clots; its fibrinogen is converted into fibrin. The small quantity of serum

which is necessary indicates that the process may depend upon the action of a ferment, or enzyme.

Enzymes.—The following are some of the characteristics of enzymes, or ferments, a class of bodies of whose nature we are ignorant, their analysis having, so far, proved impossible, owing to the difficulty of separating them from impurities, and of obtaining them in sufficient quantities.

Their activity does not exhaust or use them up; consequently—

A minute quantity of enzyme may cause the fermentation of an indefinite amount of fermentable material.

The accumulation of the products of fermentation interferes with their continued action.

Their action is retarded by cold.

There is an optimum temperature, at which an enzyme acts most rapidly: the optimum for those found in the human body is about 40° C.

They are destroyed by boiling, though in a dry condition they may be heated to a temperature of 100° C. without injury.

The activity of many enzymes is dependent on the reaction of the solution in which they are present, a neutral or slightly alkaline reaction being most favorable in the majority of cases; pepsin, however, requires a slightly acid reaction.

The chemical change resulting from their action is usually one of hydrolysis. (See page 18.) Maltase, however, while its characteristic action is the conversion of maltose (malt-sugar), by hydrolysis, into dextrose, can, if added to a strong solution of dextrose, convert a small portion of the latter into maltose. It is possible that other enzymes are capable of this *reversed zymolysis*, and that this affords an explanation of the hindering effect of an accumulation of the products of fermentation.

Finely divided platinum, paladium, and iridum, behave, in some respects, as do enzymes; for instance, they may, by hydrolysis, invert cane-sugar—that is, convert it into equal parts of dextrose and levulose. In the decomposition of H_2O_2, platinum appears to act by contact, and not by entering into the reaction.

We know no more of the method of action of ferments than we know of their composition; amongst other explanations that have been suggested are the following; according to one of these theories, the enzyme unites with the fermentable material to form an unstable compound which readily breaks down into the original enzyme, and substances which are simpler and more stable than the original fermentable material, *e. g.:*

(1) Malt-sugar + Enzyme + H_2O = Substance x.
(2) Substance x = Enzyme + Grape-sugar + Grape-sugar.

According to another hypothesis, the enzyme is in a state of molecular movement, which is, by contact, imparted to the fermentable material, renders it unstable, or increases its instability, and thus causes it to break down into simpler and more stable substances. The susceptibility of any substance to the action of a given enzyme depends upon its molecular structure.

To return to the clotting of the blood, there are other indications that the process is one of zymolysis. For instance, serum that has been boiled is no longer capable of causing salted blood or solutions of pure fibrinogen to clot; again, clotting is retarded by cold, and hastened by keeping the blood at or a little above body-temperature. It is supposed that clotting is indeed caused by an enzyme, to which the name of **fibrin-ferment** has been given. This ferment probably originates, on the shedding of blood, from the union of a nucleoproteid, derived from the white blood-cells, with

calcium. Clotting may be prevented by the addition of any substance—*e. g.*, potassium oxalate or soap—which will cause the precipitation of the soluble calcium of the plasma. It seems that contact with any foreign surface causes the white blood-cells to excrete nucleoproteid into the plasma, with the subsequent formation of fibrin-ferment; for if blood be drawn directly into oil through an oiled cannula, the formation of fibrin-ferment is very much delayed, apparently because the leukocytes are protected from the injury to which, but for the oiling of the cannula and receptacle, they would have been subjected. The prevention of coagulation by cooling the blood to 0° C. also depends, in part, upon conservation of the leukocytes.

The clotting of blood may, for the time being, be prevented by the intravascular injection of albumoses, or of a very small quantity of nucleoproteid; the injection of larger amounts of nucleoproteid causes extensive intravascular clotting.

The lungs in some unknown way lessen the tendency of the blood that circulates through them to coagulate, while the liver exerts an influence in the opposite direction.

Transfusion.—After severe hemorrhage it is sometimes necessary to increase the bulk of the patient's blood by the injection of some liquid, and the choice of this liquid is important. Since defibrinated blood always contains fibrin-ferment, it is inadvisable to inject the blood of another person, even if that person is known to be perfectly healthy, and the blood has been whipped to prevent its coagulation; the fibrin-ferment contained in it may cause intravascular clotting of the remnant of the patient's own blood. The injection of blood taken from some other animal is objectionable for the same reason, and possesses another disadvantage—

namely, that the blood of one species may destroy the cells in the blood of another species with which it is mixed; this is known as the globulicidal action.

The direct transfusion of blood from the vessel of one patient into the vessel of another is dangerous, in that the leukocytes may be injured as they pass through the connecting cannula, and thus, nucleoproteid being set free, fibrin-ferment may be formed and coagulation be caused. In consequence of the difficulties and dangers of using defibrinated blood or direct transfusion of blood from one human to another recourse is usually had to infusions of solutions of inorganic salts, subcutaneously or intravenously. A fluid for such purposes should be a perfect solution, isotonic with the blood; *i. e.*, the equivalent of an 0.85% solution of sodium chlorid, sterile, and heated to body temperature.

Calcium, potassium, and sodium salts should be used in about the following proportions to have an infusion fluid of most efficiency: Calcium chlorid, 0.026%; Potassium chlorid, 0.035%; Sodium chlorid, 0.75%.

After hemorrhage an infusion of a saline solution promptly fills the place of the bulk of blood plasma lost, and the regeneration of red blood-cells usually follows rapidly.

Osmotic Pressure. — Osmosis is not precisely understood, but the following explanation of the phenomenon, though not free from objections, may be of service.

When a substance is dissolved in a liquid, it behaves as though it were a gas; its molecules are in constant motion. The outermost layer of liquid acts as a limiting membrane, against which the molecules of the substance in solution are continually striking; the result of these impacts is a constant outward pressure, just as the molecules of a gas inclosed in a vessel are continu-

ally striking against the inner surface of the vessel and subjecting it to a pressure. In each case, the pressure is proportional to the number of molecules contained—in the one case, in a given quantity of liquid; in the other, in a given space. The larger the number of molecules, the greater the pressure.

Let a vessel containing water be divided into two compartments by a loosely stretched membrane of such a nature that water can easily pass through it, while it is entirely impermeable by albumin. If, now, some albumin be introduced into one of the compartments, *a* (Fig. 1), and be dissolved, its molecules will wander in all directions through the solution, and many of them striking against the membrane, will press it *through* the water, and cause it to bulge into compartment *b* (Fig. 2). This is possible only where the membrane is permeable by water. The albumin solution will have increased in bulk, owing to the passage of water through the membrane.

When the membrane has become taut, the passage of water from *b* into *a* will not cease, for the albumin molecules are not only striking against the membrane, but against every part of the limiting layer of the solution in *a*, including that forming the upper surface of the liquid. The tendency will be, then, to force this surface layer upward, and since no such tendency exists in *b* (for the water in *b* contains no substance in solution), water will continue to pass from *b* into *a*, and the level of the liquid in *a* will rise, while that of the water in *b* will sink (Fig. 3). This will go on until all the water has been absorbed by the albumin solution, or until the difference between the levels of the two liquids represents a hydrostatic pressure equal to the osmotic pressure of the albumin solution, at which point equilibrium will be established. A much more convenient

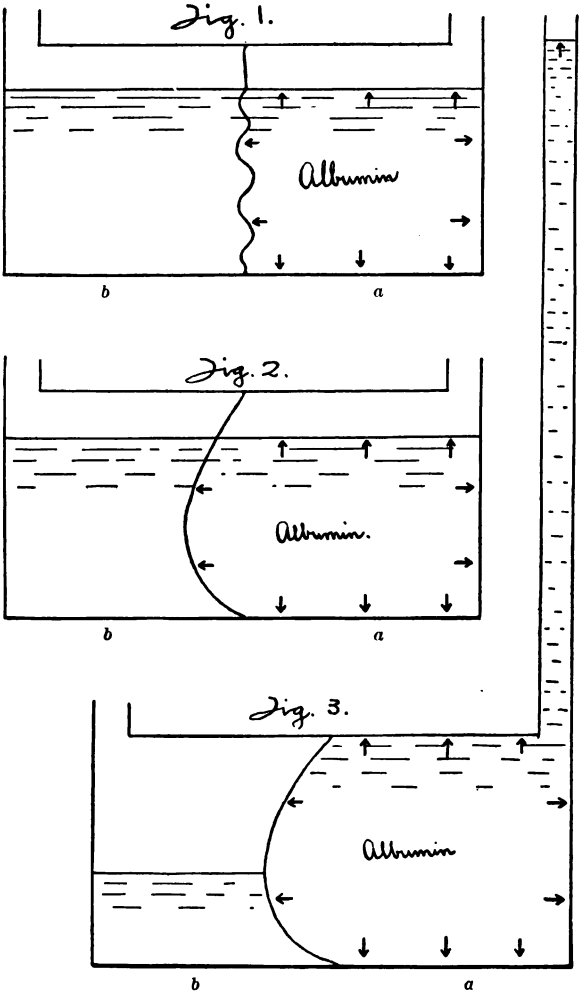


Fig. 1.
Albumin
b
a
Fig. 2.
Albumin.
b
a
Fig. 3.
Albumin
b
a

method of ascertaining the osmotic pressure of a solution is the measurement of its freezing-point.

When any substance is dissolved in water, the freezing-point of the solution is lower than that of water; the same is true if some solvent other than water be used—the freezing-point of the solution is lower than that of the solvent. The freezing-point is depressed in proportion to the molecular concentration of the solution, and, of course, in proportion to its osmotic pressure. A depression of the freezing-point by 1° C. indicates an osmotic pressure of 9,437 mm. of mercury. If, then, we find the freezing-point of a solution to be, for example, —0.02° C., its osmotic pressure must be $9437 \times 0.02 = 188$ mm. Hg.

In order to make solutions of two different substances, which shall be isotonic with one another, each substance must be dissolved in proportion to its molecular weight, and each solution made up, by the addition of water, to the same bulk. For instance, take one gram-molecule of Cane-sugar, $C_{12}H_{22}O_{11}$,—that is, 342 grams (a gram-molecule is the molecular weight of a substance expressed in grams),—dissolve it in water, and add water until the solution measures 1 liter. A solution of Grape-sugar, $C_6H_{12}O_6$, to be isotonic with the above solution of cane-sugar, must be made in the same way, with one gram-molecule, 180 grams, of grape-sugar. The freezing-point of each will be —1.8° C.; the osmotic pressure, $9437 \times 1.8 = 16{,}986$ mm. Hg.

In the case of an equimolecular solution of an electrolyte, however, the freezing-point would be lower, and the osmotic pressure higher. An *electrolyte* is a substance a certain proportion of whose molecules undergo dissociation when it is dissolved; for instance, Sodium Chlorid is, to a certain extent, dissociated, on solution, into Na and Cl ions, each ion behaving, as far

as osmotic pressure is concerned, as though it were a molecule. In the case of a salt like Mercuric Chlorid, the molecules which become dissociated split up into three ions, Hg, Cl, and Cl, so that the freezing-point will be depressed still further, and the osmotic pressure will be still higher, than in the case of an equimolecular solution of a nonelectrolyte. Solutions of an electrolyte are capable of conducting electricity; solutions of nonelectrolytes are nonconductors.

If solutions of two different substances be separated from one another by a membrane which is impermeable by each of these substances, but permeable by water, water will pass through the membrane toward the solution possessing the higher osmotic pressure. This will continue until, by the dilution of the one, and concentration of the other, the osmotic pressures of the two have been equalized; that is, provided the two liquids be kept at the same level, in order to exclude the effect of hydrostatic pressure.

If solutions of two different substances be separated from one another by a membrane which is impermeable by one of them, slightly permeable by the other, and readily permeable by water, the result may be complicated. As an example, let us take two solutions, *a* and *b*, separated by a membrane which is impermeable by the substance dissolved in *a*, slightly permeable by the substance dissolved in *b*, and readily permeable by water. If the osmotic pressure of *a* be greater than that of *b*, water will pass from *b* to *a*, but not so rapidly as it would do if *b* were pure water; for the osmotic pressure of *b* will retard its loss of water, since the majority of the molecules in *b* will, on reaching the membrane, strike against it and rebound; a few will, however, pass through into *a*, and the final result, if the experiment be sufficiently long continued, will be the complete absorption of *b* by *a*.

If, at the beginning of the experiment, the osmotic pressure of *b* be greater than that of *a*, although the final result will be the same as in the last case considered, water will at first pass from *a* to *b*, for more pull is exerted by *b*. Since, however, the osmotic pressure of *b* will be continually reduced, not only by dilution, but also by the slow diffusion of its dissolved substance into *a*, and at the same time the osmotic pressure of *a* will continually increase, owing to loss of water and gain of the substance which diffuses into it from *b*, a time must come when the two solutions are isotonic with one another, and the passage of water through the membrane will momentarily cease. The substance dissolved in *b* will, however, continue to diffuse through the membrane into *a;* this will raise the osmotic pressure of *a* above that of *b*, and water will now begin to pass in the direction of *a*. The final result will, as above, be the complete absorption of *b* by *a*.

Erythrocytes.—The chemical composition of the red cells is about as follows:

Water	90.0%.
Hemoglobin	36.0%.
Proteids	3.2%.
Lecithin and cholesterin	0.2%.
Inorganic salts	0.6%.

While amongst the inorganic salts of plasma and lymph the sodium salts predominate, in the cells potassium salts are the more abundant.

Hemoglobin is a compound proteid, which may be split up into a globulin and a pigment, *Hemochromogen*. Both these substances, apparently owing to the fact that they contain iron, possess a marked affinity for oxygen, with which they unite to form unstable compounds; in the one case *Oxyhemoglobin*, in the other, *Hematin*. Hemoglobin, Hb, and Oxyhemoglobin, HbO_2, are both

crystalline, and soluble in water. Oxyhemoglobin is scarlet in color, and is accountable for the color of arterial blood, venous blood being dark purple owing to the reduction of much of the hemoglobin. Hemoglobin also possesses an affinity for Carbon monoxid, with which it unites to form Carbon-monoxid hemoglobin, HbCO, a compound which is more stable than HbO_2. This is why the inhalation of coal-gas is dangerous; the carbon monoxid contained in coal-gas combines with the hemoglobin, and thus prevents its union with oxygen. Hemoglobin forms a still more stable compound with nitric oxid. If oxyhemoglobin be treated with an oxidizing agent, it is converted into *Methemoglobin*, which contains the same amount of oxygen as does oxyhemoglobin, but the union is a firmer one. Methemoglobin is brown in color. Each of these pigments shows, in dilute solution, a characteristic spectrum. Oxyhemoglobin shows two absorption bands between the Frauenhofer lines D and E, the band toward the red end of the spectrum being the narrower and darker of the two. Reduced hemoglobin shows one band, between the lines D and E, which is broader and less well-defined than the absorption bands of oxyhemoglobin. By means of photography, another absorption band, still more characteristic of blood pigment, may be shown between the Frauenhofer lines G and H; this is known as Soret's band.

Leukocytes, or white blood-cells, are composed about as follows: Water, 88.5 %; proteids and nucleoproteids, 9 %; and small quantities of lecithin, cholesterin, fats, inorganic salts, etc.

The leukocytes are, as we have seen, concerned in the clotting of blood; the blood platelets also probably take part in the formation of fibrin-ferment. The leukocytes possess the power of changing their shape (ame-

ement), an escape through the
the capill s (diapedesis) and
rough the is process is greatly
by the itant, the leukocytes
inflamed area, and
opism. If a small
teria be introduced
icts of bacterial ac-
end of the tube into
ontact with the leu-
h a manner that the
the direction from
ach them. It is sup-
ingest the bacteria
stance which inhibits
ukocytes of the frog
n this way the white
gainst the inroads of
ng the health of the

s are:

1. To protect the body against pathogenic bacteria (phagocytic and bactericidal action).
2. To aid in the absorption of fats from the intestine.
3. To aid in the absorption of peptones from the intestine.
4. To take part in the process of blood-coagulation.
5. To help maintain the normal composition of the blood plasma as to proteids.

ADAPTATION OF BLOOD.

Under the description of blood and its functions should be included the chemical defenses of the body against injury and disease. Clotting of blood is a great protection against injury. The acid gastric juice is de-

structive to most bacteria introduced in t But in addition to these means of assisting in ı ction of the body, there is a power of adaptation to meet the harmful agencies which may enter the blood stream, possessed by the blood plasma, and capable of great development and apparently of innumerable variations. The presence of these substances in the plasma is due chiefly to the activity of the endothelial cells lining the heart cavities and the blood vessels, and of the red and white blood-cells.

Bacteriolysins are soluble proteids of the blood plasma, destroyed by heating to 55° C., capable of destroying various kinds of bacteria.

Hemolysins are similar substances which are able to destroy the red blood-cells of another species.

The increase of bacteriolysins in the blood may be accomplished by the injection of increasing but non-fatal doses of bacteria or their products into the circulation.

The hemolytic power of blood may be developed to greater than normal degree in a similar manner.

On analysis by experimental methods it is found that the bacteriolysin or hemolysin consists of two substances, called the **immune body** and the **complement.** The bacteria or cell destroying substances of the blood cannot act upon their objects of attack without an intermediary substance, a substance, as it were, with two chemical affinities, the immune body which is found to be specific for each bacteriolysin or hemolysin which is developed, and when the action has taken place the immune body is considered to be united to the bacterial product on one side and the blood complement upon the other.

A further property of the blood is a power of **agglutinating** or clumping and rendering immobile the bac-

teria which it may be called upon to attack. This property also, though present at all times, is capable of development and increase, as is seen in the course of various diseases; as, for example, in typhoid fever, where the specific **agglutinins** or the patient's blood are so developed as to show a clumping of typhoid bacteria when the patient's serum and a culture of typhoid bacteria are brought together.

Coincident with the increase of hemolytic power developed by injecting the blood of one species of animal into another species, there are developed specific **precipitins.** If the serum is taken from a rabbit which has for a period of weeks had small subcutaneous doses of human blood serum, and is added to human blood serum, a precipitate will occur, which will not take place when such **adapted** rabbit serum is added to the blood of any other animal, except that of the anthropoid apes. This is the so-called Biological test for the source of a suspected blood.

THE LYMPH.

Lymph is formed by the filtration of plasma through the walls of the capillaries into the lymph-spaces, which lie outside the capillaries and between the cells of the various tissues. Its composition is, however, not precisely the same as that of the plasma, owing to the fact that the proteids do not pass through the capillary wall as readily as do the other constituents of the plasma. The capillaries of different parts of the body differ in their permeability, those of the liver being the most permeable, those of the lower limbs the least so; consequently, the lymph formed in different parts differs in composition; that formed in the liver may contain proteids to the extent of 6 %; that formed in the legs, about 3 %.

The force concerned in causing the filtration of the plasma into the lymph-spaces—in other words, in the formation of the lymph—is the intracapillary blood pressure. To this force are opposed the following: the slight resistance offered by the capillary wall to the passage through it of water and inorganic salts; the much more effective resistance which is opposed to the passage of proteids; and the osmotic pressure which is exerted by that portion of the proteids which does not pass through the wall, but remains within the capillaries. This portion is usually the larger. Proteids form about 8% of the plasma, and exert an osmotic pressure of about 30 mm. of mercury; the lymph contains about 3% proteids with an osmotic pressure of 10 mm. of mercury or a little more, exerted in the opposite direction; so that the balance of osmotic pressure which is effective in resisting the outward passage of lymph amounts to about 20 mm. Hg. The intracapillary blood pressure is, under ordinary circumstances, from 30 to 50 mm. Hg, and suffices to overcome the opposing forces which have been mentioned above; but if for any reason—*e. g.*, after severe hemorrhage—the intracapillary pressure falls below 20 mm. Hg, the effective balance of osmotic pressure, due to the predominance of proteids within the capillaries will cause the absorption of water from the lymph-spaces.

That portion of the lymphatic system concerned in the absorption of fat from the intestine, and the conveying of the lymph and its contained emulsified and saponified fats by the lacteals, the receptaculum chyli, and the thoracic duct, to the blood stream, illustrates best the various factors which control the flow of lymph in various parts of the body. They may be summed up as follows:

1st. Intracapillary pressure.

2d. Force of diffusion depending upon the inequality in the chemical composition of the blood plasma and the liquid outside of the capillaries, or between this liquid and the contents of the tissue elements.

3d. The force of osmotic pressure.

4th. The valves in the lymph-vessels.

5th. The negative pressure in the thorax acting upon the surface of the thoracic duct.

6th. The negative pressure in the great veins at the base of the neck acting upon the opening of the thoracic duct at its venous junction.

7th. The effect of contraction and relaxation of the skeletal, and visceral musculature.

QUESTIONS FOR CHAPTER I.

What is the physiological difference between plants and animals?

Name the properties of a living cell.

What is the source of the potential energy which is contained in food?

In what respect does bioplasm resemble dynamite?

Why is it impossible to convert fat and carbohydrate into proteid?

Why is hydrolysis accompanied by the liberation of heat?

Why are native proteids divided into two classes?

How may native proteids be removed from a solution which also contains proteoses and peptones, without removing the two latter?

What proportion of a blood clot consists of fibrin?

How does hemoglobin differ from other proteids?

How may albumins be separated from globulins?

Give the functions of the blood as a whole, and of the red cells and leukocytes independently.

What are some of the changes which occur in blood when it is boiled?

What are the effects of removing all the inorganic salts from blood?

Does the "salting" of blood prevent the formation of fibrin-ferment, or does it prevent its activity?

Does the addition of fibrin-ferment to defibrinated blood cause it to clot?

How may defibrinated blood be caused to clot?

If the coagulation of blood be prevented by rapidly cooling it to 0° C., and keeping it at this temperature until most of the cells have settled, and if the upper and lower layers of plasma be separated and warmed, which will coagulate first?

By what different methods may fibrinogen be removed from the blood, without at the same time removing the other proteids?

What effect has the addition of defibrinated blood on a solution of pure fibrinogen?

What is the effect of introducing a foreign body into the blood-vessels?

What are the agencies which may be brought into activity to resist the harmful effect of foreign substances in the blood stream?

Why does the dilution of salted blood cause it to clot?

Why does packing a wound with gauze hasten clotting?

How may we determine whether a given reaction is caused by an enzyme?

Is lymph a product of the lymphatic glands?

What is the difference between lymph and serum?

What are the important constituents of lymph?

Why does serum remain liquid at 0° C.?

How may the osmotic pressure of plasma be reduced?

Why should distilled water not be injected into the blood-vessels?

Why does an organ that is removed from the body quickly lose its irritability?

The osmotic pressure of the plasma is due chiefly to the inorganic salts which are present in small quantity. Why, then, are the proteids of greater importance in relation to the exchange of water between the plasma and lymph?

Does a 1% solution of maltose or a 1% solution of dextrose possess the higher osmotic pressure? Why?

CHAPTER II.

THE CIRCULATION OF THE BLOOD.

The Heart.—The blood is inclosed in a system of elastic tubes, the blood-vessels, a portion of which has been developed into a muscular pump, the heart, which possesses the power of rhythmic contraction and relaxation. As the heart relaxes, blood flows into it from the veins; as it contracts, blood is forced out into the arteries. The direction in which the blood flows through the heart is determined by the **valves**, which open toward the arteries only. The heart is divided into two halves, the right heart and the left; shortly after birth an opening which connects the cavities of the two hearts closes, leaving them with no communication. Each half possesses two chambers, an auricle and a ventricle; the muscular wall of the ventricle being much thicker, in each case, than that of the auricle, and the wall of the left ventricle much thicker than that of the right. This arrangement corresponds with the amount of work done by the walls of the different chambers. The blood pumped out by the right ventricle enters the pulmonary artery, and is distributed through its branches to the capillaries of the lungs, where it is arterialized; thence it flows through the pulmonary veins to the left heart, by which it is forced out into the aorta. The elastic wall of the aorta, always in a state of distention, forces the blood onward through the smaller arteries, through the capillaries, and through the veins, back to the right

heart. The distention of the aorta is due to the fact that it requires more force to quicken the flow of blood through the small arterioles and capillaries than it does to stretch the aorta and larger arteries. Thus the elasticity of the aorta and larger arteries lessens the work which is required of the heart.

Between the right auricle and ventricle is placed the tricuspid valve; between the right ventricle and pulmonary artery, and at the root of the latter, is the pulmonary set of semilunar valves. The mitral valve is set between the left auricle and ventricle, while the aortic set of semilunar valves, at the root of the aorta, separates this vessel from the left ventricle.

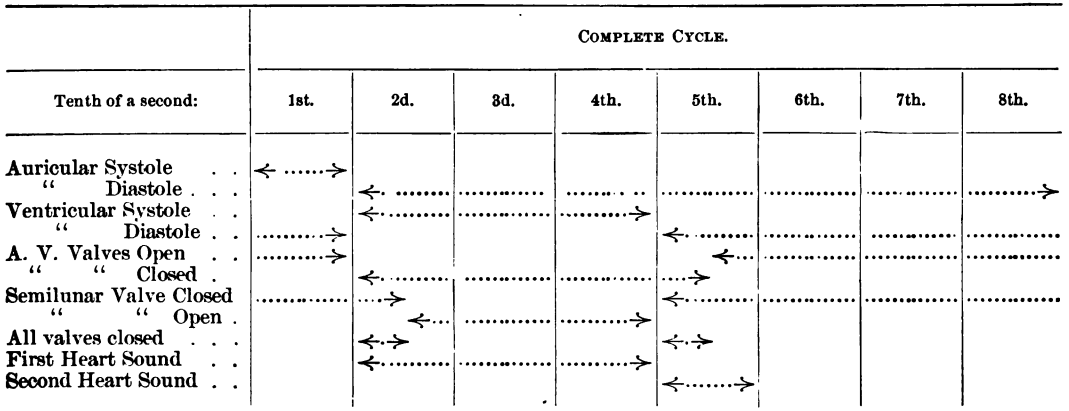
The Heart Cycle.—The cardiac beat is initiated by a contraction of the muscular fibers in the walls of the large veins close to the auricles. The contraction spreads to, and sweeps over, the auricular musculature, driving the contents of the auricles into the ventricles, and constituting the auricular systole. This merely completes the filling of the ventricle, in which, previous to the systole of the auricle, blood has accumulated by inflow, through the latter, from the veins. The auricular systole lasts but 0.1 of a second, and is followed by the systole of the ventricles. Were it not for the auricles, the flow of blood from the veins into the heart would be checked during the ventricular systole; as it is, the auricles not only assist in the filling of the ventricles, but constitute a time-saving reservoir which is of special value when the heart rhythm is rapid.

As the ventricles fill, the free edges of the auriculoventricular valves are carried upward and approach one another, their complete closure being effected by the rise of pressure within the ventricles, at the beginning of ventricular systole. The intraventricular pressure rises rapidly as the systole proceeds, the back-

flow of blood into the auricles being prevented by the tricuspid and mitral valves, which are held in place by their tendinous cords; while the outflow into the arteries is, for the moment, prevented by the semilunar valves, which are kept closed by the higher pressures in the pulmonary artery and aorta. As soon, however, as the pressure within the ventricle rises, in the one case, higher than that in the pulmonary artery, in the other, above that in the aorta, the semilunar valves must open as the blood is ejected by the ventricles into the arteries. The ventricles probably never completely empty themselves, and they are far from doing so when the heart is beating slowly. Then follows the ventricular diastole, or period of relaxation and rest, at the beginning of which the pressure within the ventricle falls below that in the aorta, the semilunar valves being closed in consequence. A short interval elapses before the intraventricular pressure falls below that within the auricle, and until this point is reached the auriculo-ventricular valves must, of course, remain closed. The whole series of events just described occurs simultaneously in the right and left hearts, and constitutes a heart cycle. When the heart beats with average frequency,—that is, seventy-two times a minute,—each cycle lasts about 0.8 of a second, and may be tabulated as in Table 2 (p. 42).

It will be noticed that while the auricular systole lasts 0.1 of a second, and the diastole 0.7, the systole of the ventricle occupies 0.3, and its diastole 0.5 of a second, the ventricular cycle beginning 0.1 of a second later than that of the auricle, and lasting to the end of the first tenth of a second in the succeeding auricular cycle. When the frequency of the heart-beat is increased, each cycle is, of course, shortened, this reduction being accomplished, for the most part, at the

TABLE 2.


COMPLETE CYCLE.
Tenth of a second:
1st.
2d.
3d.
4th.
5th.
6th.
7th.
8th.
Auricular Systole
" Diastole
Ventricular Systole
" Diastole
A. V. Valves Open
" " Closed
Semilunar Valve Closed
" " Open
All valves closed
First Heart Sound
Second Heart Sound

expense of the diastole, the systole of the ventricle lasting almost as long as usual.

The **behavior of the valves** depends upon the relative height of the pressure on either side of them; the auriculo-ventricular valves, for instance, remain closed as long as the pressure within the ventricle is higher than that in the auricle; when the pressure within the auricle rises above that in the ventricle, they open, and remain so until the intraventricular pressure again predominates. In the same way, the semilunar valves are kept closed by an arterial pressure that is greater than the intraventricular pressure, and give way when the ventricular rises above the arterial. It will be noticed that both sets of valves are, for two short periods, closed at the same time.

The **rate** at which the heart beats is governed by the central nervous system, which, in this respect, exerts its control chiefly over the auricles, the auricular rhythm setting the pace for the ventricles. The auricular stimulus is probably transmitted, not by nerve-fibers, but by the contraction of a few muscle-fibers connecting the auricles with the ventricles. If the auricles are caused to stop beating by the stimulation of the pneumogastric nerve, the ventricles, after a brief pause, begin to beat with a much slower rhythm of their own.

Although the central nervous system controls the heart-beat, it is by no means essential to its continuance, as may be shown by removing the heart from the body, when, if properly supplied with oxygenated blood, it may go on beating for hours. The cardiac muscle itself seems to possess an inherent power of rhythmic contraction, for even small isolated pieces of the ventricle which appear to contain no nerve-cells will beat rhythmically if supplied with arterial blood.

Heart Sounds.—If the ear be placed against the

chest-wall, two sounds are heard each time the heart beats. The first accompanies the ventricular systole, and is more prolonged than the second, which is diastolic (see Table 2). The **first sound**, which seems to be compound, is probably produced in part by the contraction of the ventricle, and in part by the vibration of the auriculo-ventricular valves on closure. Each ventricle takes part in the production of the first sound. Disease of either of the auriculo-ventricular valves produces a change in the valvular element of the sound, which, in the case of mitral abnormality, is best appreciated by placing the ear, or stethoscope, over the fifth left intercostal space, at the point where the apex-beat of the left ventricle may be seen or felt; evidence of tricuspid error being best heard just to the right of the sternum, at about the same level.

The **second sound** occurs at the beginning of the ventricular **diastole**, and is due to the vibration of the semilunar valves at, or just after, their closure. The **aortic sound** is most clearly heard at the point where the second *right* costal cartilage joins the sternum; while the closure of the **pulmonary** semilunar valve is most distinct over the second *left* intercostal space, close to the sternum. It is, however, impossible to distinguish between the normal aortic and pulmonary sounds, though an abnormality in one set may be located in this way.

If **the rate at which the blood flows** through vessels of different size be compared, it will be seen that the larger the vessel, the greater the speed. In the aorta the blood flows most rapidly, for the sectional area of this vessel is smaller than the united sectional area of its branches, consequently the blood, having less room, must flow more quickly. The rate of flow is inversely proportional to the **width of bed.** The united sectional

area of the systemic capillaries has been estimated to be as much as 800 times that of the aorta; in this district, then, the stream is sluggish. As the blood flows from the capillaries into the small veins, the width of bed decreases, and the stream quickens; in large veins the rate will approach, but never equal, that in the aorta. The velocity of the circulation, as a whole, of course increases or decreases with a change in the rate and strength of the heart-beat.

Blood Pressure.—The blood as it flows through the vessels is under constant pressure. This pressure is the product of the propelling force exerted by the heart, and the resistance offered to the flow by hydraulic friction. During the diastole of the ventricle, the flow is kept up by the elastic and overfilled aorta and larger arteries. As liquid flows through a tube, friction exists between its particles; and the nearer the wall of the tube, the greater the friction; therefore, if we compare the flow of liquid through a large tube with its flow through a number of small tubes, the united sectional area of which is equal to the sectional area of the large tube, we shall find that it meets with much more resistance in the small ones; for a much larger proportion of the liquid will flow in the neighborhood of the tube-wall, and the friction will be greater. The blood, then, will meet with most resistance on passing through the innumerable arterioles and capillaries, into which the larger arteries divide; this is usually spoken of as the **peripheral resistance.** The overcoming of this peripheral resistance uses up most of the heart force, and, by the time the blood reaches the veins, it flows under but little pressure, which, however, suffices to carry it as far as the right heart. The fall in pressure is continuous from the beginning of the aorta to the ending of the veins, for friction comes into play along the whole route,

though in the larger vessels it is but slight. In the arteries the fall is a gradual one, but it becomes abrupt in the arteriole and capillary district, while in the veins the pressure again decreases slowly.

The blood pressure is variable, especially that in the arteries. As there are two factors in the production of the blood pressure, so there are two main causes concerned in bringing about its variation; namely, (*a*) a change in the propelling force, the heart-beat, and (*b*) a change in the peripheral resistance. A third cause consists in an alteration of the capacity of the vessels, more especially of the large veins. An increase in the rate and strength of the heart-beat naturally raises the pressure in the arteries and capillaries, and since the heart transfers blood from the veins into the arteries, the pressure in the large veins must under these circumstances be lowered. When the activity of the heart is depressed, the resulting changes in blood pressure are the opposite of those just enumerated. While elastic tissue is a characteristic feature in the walls of the large arteries, in the arterioles muscular tissue predominates, and gives to these small vessels the important property of **varying their caliber.** With a change in their size, the resistance which they offer to the blood flow also varies; a wide-spread constriction of the arterioles resulting in a marked rise in arterial pressure, while a great fall accompanies their general relaxation, for the blood, under these circumstances, flows more readily from the arteries into the capillaries. The highest possible arterial pressure is attained by a general constriction of the arterioles, accompanied by a strong and rapid heart-beat. A very low pressure will result from a general dilatation of the arterioles and a slow, weak heart-beat; if at the same time the walls of the large veins and of the branches of the portal vein relax, the

blood will tend to stagnate in these veins, and, since little blood will reach the heart, but little can be pumped into the arteries, in which the pressure will fall to a dangerous extent.

Nervous Control.—The heart is controlled by the central nervous system, through two sets of nerves; one set, arising from the Cardio-inhibitory Center, lessens its activity; the other, carrying impulses from the Accelerator or Augmentor Center, quickens and strengthens the beat. The cardio-inhibitory nerve-fibers reach the heart through the pneumogastric, and probably exert their influence over the heart muscle, not directly, but through the mediation of nerve-cells which are situated in the wall of the organ. On division of both pneumogastric nerves, in the neck, the heart beats more rapidly, for the controlling influence of the center is thus cut off. If the end of the peripheral portion of one of these divided nerves be stimulated with electric shocks, the heart-beat will become slow, or, if the current be strong, will stop for a short time. The auricles may, in this way, be prevented from beating for an hour or more if the stimulation be kept up; but the ventricles, after a short pause, begin to beat at a slower rate than before. The diastole is very much prolonged, and, of course, gives time for the accumulation within the heart of more blood than usual between beats; the ventricle thus dilated fails to empty itself; indeed, to such an extent is this the case that a slowly beating heart may, at the end of its systole, contain more blood than it usually contains at the beginning of the contraction. This residual blood will, in the succeeding diastole, retard the inflow from the veins, and, in consequence, less blood will enter the heart in a given time, and the pressure in the large veins will rise. Since less blood enters the heart in a given time, less will be pumped out into

the arteries, and the arterial pressure falls. Although the output of the ventricle is decreased, the contraction volume—that is, the amount forced out by a single contraction—is increased. To repeat, then, a slow heart-beat results in a dilatation of the ventricle and a rise of venous pressure, a lessened output, and a fall of arterial pressure.

The **cardio-inhibitory center** is situated in the spinal bulb, and is bilateral. It is continually active, and this tone may be increased or decreased in a variety of ways; for instance, a rise of arterial pressure increases its activity, the importance of this fact being apparent, for any abnormal rise of pressure will tend to bring about its own fall by lessening the output of the heart, through stimulation of this center. The center is not only affected by the pressure at which the blood flows through the neighboring vessels, but it is also sensitive to its chemical composition; if the blood becomes unusually venous, the center is stimulated. A **reflex slowing of the heart** may be caused by the stimulation of various sensory nerves; for instance, the nasal branch of the trifacial, as on the inhalation of chloroform or ammonia vapor into the nostrils. A reflex event is one which is produced by the passage of an afferent nerve-impulse from the periphery to a center, the center responding by the dispatch of an efferent (outward) impulse which brings about the event, be it the contraction of a muscle, secretion by a gland, or inhibition of the heart. A reflex slowing of the heart is readily caused by stimulating the afferent nerve-fibers of the pneumogastric; these fibers normally carry afferent impulses from the lungs, heart, liver, stomach, etc., to the spinal bulb, but not all of them necessarily reach the cardio-inhibitory center. During expiration the heart beats slowly, owing to afferent

impulses from the lungs, which, on reaching the bulb, affect the center either directly or through the intervention of the respiratory center. It may also be inhibited by afferent nerve impulses, as, for instance, through the glossopharyngeal nerve during swallowing; this may, however, be another case of irradiation from the respiratory center. An inhibition of the cardio-inhibitory center of course allows the heart to beat more rapidly. The quickening of the heart-beat which follows the administration of atropin depends upon a partial or complete paralysis of the endings of the inhibitory fibers in the heart. The center is also under the influence of the emotions.

The **cardio-augmentor center** is probably also situated in the spinal bulb; the nerve-fibers arising from it descend the spinal cord as far as the upper end of the thoracic region, where they probably end, but make physiologic connection in the gray matter with nerve-cells whose fibers pass out through the upper thoracic ventral nerve-roots; in the dog, through the second and third. They join the sympathetic chain, and probably end in the ganglion stellatum, where a second cell station intervenes, the fibers originating from the ganglion cells passing to the heart muscles. This last set of nerve-fibers come under the head of what are known as **post-ganglionic** fibers of the sympathetic system, in contradistinction to the fibers of the second set mentioned, the **pre-ganglionic** sympathetic fibers, which, originating from cells situated in the gray matter of the spinal cord, end in sympathetic ganglia. The nervous chain which connects the spinal cord with involuntary tissue, such as plain muscle, cardiac muscle, and glandular epithelium, usually, if not always, consists of two links—pre-ganglionic and post-ganglionic nerve-fibers. If the augmentor center possesses tone,

—that is, is continuously active,—as seems probable, its influence over the heart-beat is not so marked as that of the inhibitory center. The stimulation of the augmentor nerves increases the strength of both the auricular and the ventricular contraction, the output of the venticle is increased, the venous pressure is lowered, and the arterial pressure raised. During muscular exercise the augmentor center is stimulated by the chemical waste products of muscular metabolism, which proceeds more rapidly during activity than during rest. A rise of body-temperature also directly stimulates the center. A reflex quickening of the heart may be provoked by the stimulation of almost any nerve-trunk, but is usually followed by slowing, owing to the simultaneous or subsequent stimulation of the inhibitory center through the same channel. As is well known, the heart-beat may be quickened by the emotions.

Nervous control is not the only cause of variation in the strength of the heart-beat; the quantity and quality of the **coronary blood supply** also exert an influence. The effect of an alteration in the amount of blood supplied to the heart is much more marked in regard to strength than frequency. The ventricle beats more strongly when its coronary blood supply is increased. A high arterial blood pressure is favorable to a strong heart-beat, unless the ventricle becomes dilated in consequence, in which case the coronary circulation is retarded. A moderately high pressure also increases the force of the heart-beat, owing to the fact that muscles work to better advantage against a certain amount of resistance. The quality of the blood is important, especially in regard to the amount of oxygen contained.

The **variation of the peripheral resistance** is also

under the control of the central nervous system. There exists in the spinal bulb a center, known as the **vaso-constrictor center,** which exerts an influence over the muscular walls of the vessels, most evident in the case of the arterioles. As in the case of the cardio-inhibitory center, the activity of this center is continuous, and its tone is variable. Like the inhibitory center, it acts as a regulatory mechanism whereby the blood pressure is kept fairly constant. If the arterial pressure falls, this center becomes more active, and brings about a constriction of the arterioles, thus raising the peripheral resistance, and with it the arterial blood pressure. It is also stimulated by a venous condition of the blood, the arterial pressure rising to a great height during dyspnea, in spite of the simultaneous inhibition of the heart. Its activity is reduced by certain drugs, such as chloroform, ether, alcohol, etc. It may be indirectly stimulated through almost any afferent nerve; for instance, the application of cold to the skin, by stimulating the cutaneous nerves, and thus indirectly influencing the constrictor center, brings about a reflex paling of the skin. On the other hand, the application of warmth causes a reflex dilatation of the cutaneous vessels, by inhibiting the constrictor center. One afferent nerve which transmits impulses from the heart to the spinal bulb, and is known as the **depressor nerve,** is of special importance through its relation to this center, and consequent influence on the regulation of the blood pressure. When the arterial pressure rises unduly, the intracardiac pressure must also rise, and in so doing stimulates the endings of the depressor nerve; this results in the passage through the nerve of impulses which, on reaching the bulb, inhibit the constrictor center. The activity of the center being reduced, the arterioles are allowed to

dilate, the peripheral resistance is lessened, and the arterial pressure falls. The depressor nerve thus serves as a safeguard against any undue rise of arterial pressure, and affords the heart protection against overwork. As in the case of the centers which regulate the heart-beat, this center also may be influenced by the emotions; for example, blushing is due to its inhibition by nerve impulses descending from the brain.

The control exercised over the vessels by the constrictor center is specialized, for although it maintains a general vascular tone, it does not, as a rule, cause marked contraction of all the arterioles at the same time; if the vessels of the skin be unusually constricted, those of the viscera are allowed to dilate, and vice versa. This arrangement insures a more even blood pressure than would otherwise exist.

The **course of the constrictor nerve-fibers** resembles, to a certain extent, that followed by the cardio-augmentors. The nerve-fibers originating in the center pass down the spinal cord, to end in the gray matter at different levels of the thoracic and upper lumbar regions. The ends of the fibers make physiologic connection with nerve-cells whose axons, usually of small caliber, pass out through the anterior spinal nerve-roots to enter the sympathetic system as pre-ganglionic fibers. They end in one or other of the sympathetic ganglia in contact relations with cells whose axons, post-ganglionic fibers, usually nonmedullated, are distributed to the arterioles in almost every part of the body. The post-ganglionic fibers which innervate the vessels of the skin reach their destination by passing through a gray ramus communicans to the spinal nerve supplying the cutaneous area in question (Fig. 4.); those for the visceral arterioles do not reenter a spinal nerve, but reach the viscera through the sympathetic (Fig. 5).

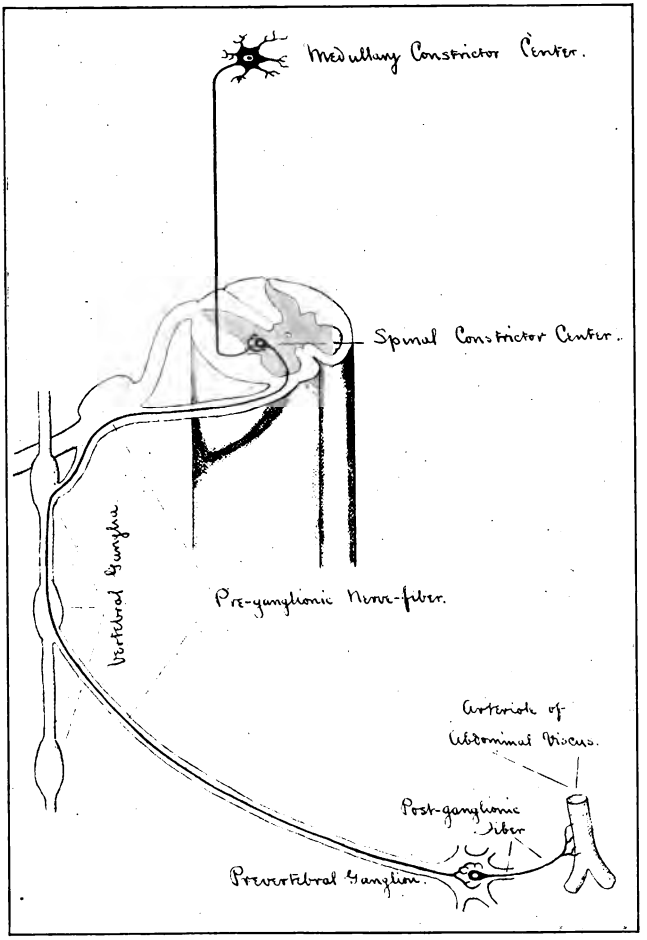

Medullary Constrictor Center.
Spinal Constrictor Center.
Vertebral Ganglion
Pre-ganglionic Nerve-fiber.
Arteriole of
Abdominal Viscus.
Post-ganglionic
fiber
Prevertebral Ganglion.

Fig. 4.

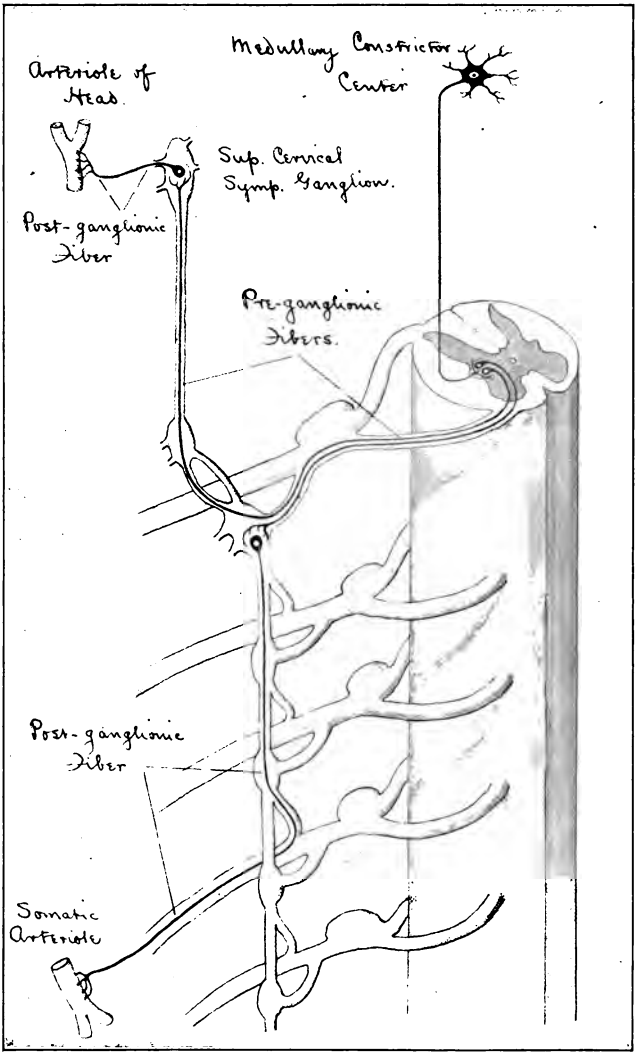

Medullary Constrictor Center
Arteriole of Head.
Sup. Cervical Symp. Ganglion.
Post-ganglionic Fiber
Pre-ganglionic Fibers.
Post-ganglionic Fiber
Somatic Arteriole

Fig. 5.

The pre-ganglionic fibers for the head pass up the cervical sympathetic and end in the superior cervical sympathetic ganglion (Fig. 4).

Since all the vasoconstrictor fibers originating from the center pass down the spinal cord to the thoracic region, division of the cord in the cervical region must be followed by a great fall of blood pressure, for all the vessels in the body dilate; if, however, the animal be kept alive, the vascular tone will, after a time, gradually reappear, depending apparently on an increased irritability of the spinal cord, the cells from which the pre-ganglionic fibers originate acting as vicarious constrictor centers. If, now, the thoracic cord is destroyed, the vascular tone again disappears for a time, but is partly reestablished either through the influence of the sympathetic ganglion cells from which the post-ganglionic fibers spring, or owing to the independent contraction of the muscular wall of the vessels.

Some **veins** have been shown to possess a supply of vasoconstrictor nerves; for example, the portal veins. Since the administration of chloroform or ether tends to paralyze the vasomotor center, it is very important that an anesthetized patient be kept in a horizontal position, for, otherwise, the blood will accumulate in the relaxed abdominal veins, and will, by force of gravity, be prevented from reaching the heart.

Scattered through the different regions of the spinal cord and bulb are **vasodilator nerve-centers**, whose cells give off axons which, for the most part, follow the same course as the pre-ganglionic vasoconstrictors; no chief vasodilator center has been proved to exist in the bulb. The existence of vasodilator fibers in a mixed nerve-trunk may be demonstrated by special methods of stimulation; there are, however, some nerves which

contain vasodilators unmixed with vasoconstrictors. The chorda tympani nerve is one of these, and transmits to the sublingual and submaxillary glands vasodilator fibers which leave the bulb in the seventh cranial nerve. On stimulation of this nerve, the arterioles in the glands dilate, and the blood flows through them more rapidly than before. The pre-ganglionic fibers of the chorda tympani end in contact with submaxillary and sublingual ganglion cells, from which post-ganglionic fibers are distributed to the arterioles. The post-ganglionic vasoconstrictor fibers for the arterioles of these glands come from the superior cervical sympathetic ganglion by way of the carotid plexus.

During the **activity** of an organ its blood supply is increased, the maximum supply being afforded by the dilatation of its own arterioles, the constriction of the arterioles in other parts of the body, and a strong and rapid heart-beat.

The Pulse.—If the blood flow through an artery be compared with that through a vein, a marked difference will be observed; the flow through the artery is remittent, that through the vein is constant; the artery pulsates, the vein does not. The arterial pulse consists in a rhythmic enlargement and subsequent shrinkage of the vessel due to slight variations in arterial blood pressure. The enlargement is caused by the sudden rise of pressure which follows the ventricular systole. As the ventricle forces out its contents the aortic pressure is raised; this rise is rapidly transmitted throughout the arterial system, the vessel-wall of each succeeding portion expanding as it is reached by the wave of heightened pressure. The slight delay in the transmission of the pulse to the more distant arteries may be readily appreciated by simultaneously feeling the carotid, and the radial pulse. Were the arteries rigid tubes, the

transmission of the pulse would be instantaneous; and, as it is, the higher the pressure already existing in the arteries, the more rapidly the pulse travels; for when the pressure is high, the vessel-wall, already tightly stretched, is less capable of further expansion than when the pressure is low. When the pressure is high, the pulse will, for the same reason, be small. A large pulse occurs when the heart-beat is strong and the pressure, owing to peripheral dilatation of the arterioles, is comparatively low. The small pulse of high pressure is hard, or incompressible; that is, it will be more difficult to flatten the artery with the finger than when the pressure is low, a low pressure pulse being soft and compressible. A small, hard pulse indicates high blood pressure; a large, soft pulse indicates low pressure and strong heart-beat; a small, soft pulse indicates a weak heart-beat and low pressure.

The blood flows through the capillaries and veins in a constant stream, the pulse having been extinguished by the resistance offered by the arterioles. As before stated, it requires less force to stretch the elastic arteries than to quicken the flow past the peripheral resistance, consequently each time the ventricle contracts, the quantity of blood ejected is for the moment accommodated in the arteries. The heart-force thus transmitted to and stored in the arterial wall is during diastole again transferred to the blood stream, the arteries being allowed the period of a whole heart cycle for emptying into the capillaries the quantity of blood which they receive during one systole. In case the arterioles of a limited area be dilated, the general arterial pressure remaining high, a pulse will appear in the small veins of this area, and the blood entering the veins will be arterial in color, for, owing to the quickening of the blood stream, a smaller proportion of the oxyhemoglobin will be reduced.

If the **form of the pulse-wave** be recorded, it is found to consist in the sudden rapid expansion of the vessel, or sudden rise of pressure within the vessel, followed by a more gradual decrease in size or fall of pressure, the fall being slightly irregular owing to the occurrence of minor pressure waves. These latter are more prominent when the arterial tension is comparatively low and the heart-beat strong. The most marked of these secondary waves is known as the **dicrotic wave**; it originates in the aorta immediately after the closure of the aortic valve, and is transmitted through the arteries in the wake of the main pulse-wave. It is probably caused by the closure of the valves.

The arterial blood pressure rises and falls slightly as a result of **respiration.** The reason for this is that enlargement of the thorax tends, not only to cause the inspiration of air, but also to aspirate blood into the intrathoracic veins and heart; while on collapse of the chest during expiration, the entrance of blood is less favored, and during forcible expiration is retarded. Consequently, the right heart receives and pumps during inspiration more, and during expiration less, blood into the pulmonary vessels. At the beginning of inspiration there is a slight delay in the reception by the left heart of the surplus blood, for the lungs on inflation accommodate more blood than before, and thus even reduce the amount reaching the left heart. On the other hand, just at the beginning of expiration the supply of blood to the left heart is still further increased, for the excess of blood contained by the inflated lungs, on their collapse, passes to the left heart. The effect, then, of the respiratory movements of the thorax is that the left heart also, after a slight delay, receives and pumps more blood during inspiration, and thus raises the arterial pressure; while, during expira-

tion, after a momentarily increased supply, it receives and pumps less blood, and the arterial pressure falls.

Venous Circulation.—The blood in the veins flows under very low pressure, for most of the heart-force has been used up in carrying it past the peripheral resistance. Its flow, however, receives material assistance through the contraction of the skeletal and visceral musculature, and through the aspiration of the thorax. When a muscle contracts, it compresses the veins in its neighborhood, and, since they are provided with **valves**, helps to press the blood onward toward the heart. Forcible expiration of course retards the passage of blood into the thorax.

The pressure in the distal veins does not fluctuate; is highest at the capillaries, and decreases as the heart is approached. At the upper border of the thorax the great veins in the neck show a variation in pressure due to the greater ease of emptying during inspiratory increase of thoracic negative pressure. On expiration the veins are seen to fill and on inspiration to empty, giving the appearance of a pulse to this **respiratory variation of pressure.** For about an inch and a half above the thorax the suction effect of the intrathoracic negative pressure is so great as to cause an **intravenous negative pressure** of a slight degree, usually only during inspiration.

A true **venous pulse** may occur under two conditions physiologically. If a gland such as the submaxillary is stimulated vigorously to increased activity the freedom of the capillary path through the gland is so great, owing to capillary dilatation, that the arterial pulse is communicated through the capillaries and appears in the veins leaving the gland. Owing to the absence of valves at the entrance of the venæ cavæ into the right auricle the auricular systole causes a re-

gurgitation of blood into the veins, and a resulting venous pulse perceptible for a distance, which depends upon the force of cardiac contraction, and the varying pressure in the great veins, and may often be seen high in the neck in the external jugular vein.

QUESTIONS FOR CHAPTER II.

What determines the moment at which the cardiac valve opens and closes?

Why are the auriculo-ventricular and semilunar valves never open at the same time?

Does blood enter or leave the ventricle in the interval between the first and second heart-sounds?

Does blood enter or leave the ventricle in the interval between the second and first sounds?

If the auriculo-ventricular valves be insufficient, during what period of the heart cycle will blood escape from the ventricle into the auricle?

If the aortic valve be insufficient, during what period of the cycle will blood flow back from the aorta into the ventricle?

Of what accompanying event should we make use in distinguishing the first from the second heart-sound?

If while the force which propels liquid through a tube remains constant the resistance be varied, how is the expenditure of the propelling force modified?

Why is the pressure in the aorta higher than that in the small arteries?

Which travels most rapidly, the pulse or the blood stream?

When the pulse is large, what is the condition of the arterioles?

When the heart is beating strongly, how can you determine the extent of vascular tone?

What sort of pulse accompanies dyspnea?

Why should the dicrotism of the pulse be exaggerated when the peripheral resistance is low?

What different circumstances tend to the production of a capillary pulse?

How does it happen that not only the auricle, but the ventricle

also, beats more slowly during increased activity of the inhibitory center?

What is the result of inhibiting the cardio-inhibitory center?

Why should division of both pneumogastric nerves lower the pressure in the large veins?

In what respect would the regulation of the blood pressure be modified by destruction of the cardio-inhibitory center?

Why should compression of the aorta cause the heart to beat more slowly?

Through what two channels may one organ influence another?

How is the blood-flow through the small vessels affected by loss of arterial elasticity?

What importance do you attach to the position of a patient during chloroform or ether anesthesia?

Compare the effects on blood pressure of the division of the spinal cord in the cervical and in the lumbar regions.

How many neurones are concerned in the control exercised by the constrictor center over a single arteriole?

How can it be determined whether the control exercised by a center is continuous?

How does bleeding modify vascular tone?

How does indirect differ from direct stimulation of a center?

What conditions of the circulatory system may lead to fainting?

Of what importance is the intracapillary blood pressure?

If all the nerves of a limb have been divided, would it be possible, by causing the muscles of this limb to perform work, to influence the heart-beat?

How does severe hemorrhage cause dilution of the blood?

How does a rise of arterial pressure tend to concentrate the blood?

How does the concentration of the blood tend toward a rise of blood pressure?

What nervous mechanism opposes these two tendencies?

In what particulars is the existence of the vasoconstrictor center a source of economy to the body?

What different vascular conditions may lead to a paling of the face?

What class of vessels is the seat of every important alteration in the composition of the blood?

In what organ is lymph most rapidly formed?

In the absence of the vasoconstrictor center, how could the blood supply of a given organ be modified according to its needs?

In what respect would the regulation of the blood pressure be interfered with by division of both depressor nerves?

Would the division of the cervical sympathetic nerve have any effect on the color of the face?

Would you class the vasodilators as vasomotor nerves?

Is constant standing or walking the more productive of varicose veins?

How can we afford the greatest voluntary assistance to the entrance of venous blood into the heart?

Why does putting a cold object, such as a key, down the back tend to stop epistaxis?

How are the lower limbs affected by compression of the iliac veins?

How would you expect the size of the heart to vary during dyspnea?

What effect on intrathoracic pressure has the systole of the ventricles?

If the heart be emptied of blood and be caused to beat, which of the heart-sounds will be heard?

How do you know that the slow rate of blood-flow through the capillary district is due to the width of bed and not to resistance?

Explain the occurrence of a venous pulse.

CHAPTER III.

RESPIRATION.

THE **function of the lungs** consists in the exposure of the blood to the air, whereby an exchange of gases between the air and the blood is rendered possible. This exposure is, however, totally ineffective, the lungs valueless, unless their alveoli are constantly ventilated. The **ventilation of the lungs** is accomplished by the respiratory muscles, which by their contraction bring about variation in the capacity of the thorax, and consequently in that of the lungs. The inner surface of the lung and the outer surface of the thorax are both exposed to the atmospheric pressure; the two are thus held closely in contact with one another by a pressure of fourteen pounds to the square inch, and every movement of the chest-wall must be accompanied by a similar expansion or diminution of the lung. An enlargement of the thorax will therefore, by increasing the capacity of the lungs, lower the pressure within them, and, if the glottis be open, lead to the entrance of air.

The muscles which may assist in the enlargement of the thoracic cavity and lungs, and thus act as **muscles of inspiration**, are the diaphragm, which on contraction increases the vertical diameter of the chest, and the scaleni, levatores costarum, serrati postici superiores, external intercostals, and intercartilaginous portion of the internal intercostals, which all take part in raising the ribs, and thus increasing the lateral and antero-

posterior diameters. These diameters of the chest are increased by raising the ribs, owing to the obliquity of the costovertebral hinge. Quiet **expiration** is accomplished, without the aid of muscular contraction, by the elastic recoil of parts which are distorted during inspiration, such as the costal cartilages, the abdominal wall, and the lungs, and by the weight of the ribs, sternum, thoracic muscles, etc. In forced expiration, the diaphragm is pushed upward by the abdominal viscera, through the contraction of the abdominal muscles, while the ribs are drawn downward by the contraction of the triangulares sterni, interosseous portion of the internal intercostals, etc.

Even when the inspiratory muscles are at rest, there exists, between the layers of the pleuræ, a **negative pressure**; that is, a pressure less than atmospheric pressure. This is due to the fact that a certain amount of the atmospheric pressure is consumed in holding the lung in contact with the chest-wall, the remainder being exerted, through the lung, against the inner surface of the thorax and the outer surface of the heart and vessels. The lungs are not large enough to fill the thoracic cavity unless they are inflated, and their inflation requires a small amount of force. If the interpleural pressure be measured when the respiratory muscles are quiescent, or after death, it will be found to be about 754 mm. of mercury, or about 6 mm. Hg less than atmospheric pressure; a negative pressure, then, of 6 mm. Hg. At the end of a forcible inspiration the interpleural pressure may fall as low as 730 mm. Hg, for the lungs are further inflated and, of course, offer more resistance to the inflating force—the atmospheric pressure. The interpleural pressure is always lower than the intrapulmonary pressure, though during forcible expiration it may rise above atmospheric pressure.

If the chest-wall be pierced, so that air can enter the interpleural space, the outer as well as the inner surface of the lung being now exposed to the full atmospheric pressure, the lung, owing to its own elasticity, will promptly collapse. If both sides of the thorax be perforated, respiration must cease, for, since the elasticity of the lungs will resist the entrance of air, through the trachea, into themselves, an enlargement of the chest will only result in the entrance of air into the interpleural spaces. The importance of the interpleural negative pressure, in respect to the flow of blood through the veins into the chest, has been already mentioned. The outer surface of the heart and large intrathoracic vessels is subjected, when the thorax is at rest, to a pressure of only 754 mm. Hg, while the veins which lie outside the chest are exposed to the full atmospheric pressure—760 mm. Hg; it is evident, then, that blood will be forced from points where the veins are more, to a point where they are less, compressed. Inspiration will further this tendency; expiration will lessen it, and, if forcible, will prevent the entrance of blood.

Respiration may seem to assume one of two types, diaphragmatic or costal, but under normal conditions of body movements both the diaphragm and the thoracic muscles enter into every respiratory movement. Position of the body, clothing, or habit may modify the normal freedom of respiratory movement, and it is seen that women usually breathe more costally than diaphragmatically, and that the reverse is true with men.

In quiet breathing the chest is neither expanded nor contracted to the full extent possible, so that the ventilation of the lungs is not so complete as might be. The amount of air ordinarily inspired and expired is about 500 c.c., and is known as the **tidal air**; in addition to

this, an amount, which varies with the capacity of the chest, and is called the **complemental air,** can be inspired, the average quantity being in the neighborhood of 1500 c.c. After the expiration of the tidal air, about 1500 c.c. more may be expelled, this volume being known as the **reserve,** or supplemental air. These three volumes taken together, and amounting to 3500 c.c., are called the **respiratory, or vital, capacity.** Not all the air can be expelled from the lungs; there remains after the most forcible expiration about 800 c.c.—the **residual air.**

The division of the cavity of the lungs into innumerable small alveoli enormously increases the respiratory surface, which is estimated as being 90 square meters.

On its way through the upper air-passages the temperature of the inspired air is raised or lowered to that of the body; it is moistened, unless already saturated with water; and, to a certain extent, purified from particles of foreign matter which adhere to the moist mucous membrane, and are carried toward the mouth and nose by the movements of the cilia.

Respiration may be divided into external respiration, the exchange of gases between the air and the blood which occurs in the lungs; and internal respiration, the exchange of gases which takes place between the blood and lymph and the tissues.

External Respiration.—Diffusion goes on rapidly between the alveolar air and the tidal air that is inspired, the latter losing oxygen to the extent of about $4\frac{1}{2}$ volumes per cent., and gaining about 4 volumes per cent. of carbon dioxid. The ratio existing between the amount of oxygen which disappears, and the volume of carbon dioxid which appears, is known as the **respiratory quotient** $\frac{CO_2}{O_2}$. The respira-

tory quotient indicates the extent to which the oxygen absorbed is used in the oxidation of carbon; this varies with circumstances—for example, with the diet. On a purely carbohydrate diet the quotient will approach unity, for sufficient oxygen is contained in the carbohydrate molecule to oxidize its hydrogen; on the other hand, a fatty diet will reduce the quotient, for in a molecule of, for instance, stearin, $C_3H_5(C_{18}H_{35}O_2)_3$, there are 110 atoms of hydrogen to but 6 of oxygen. The quotient on a proteid diet is intermediate between the two. During starvation the respiratory quotient falls, since the animal lives on its own store of fat and proteid, the amount of carbohydrate in the body being very small. Exercise raises the quotient, owing to the fact that muscular work is done for the most part at the expense of carbohydrates.

The exchange of gases which occurs between the air in the pulmonary alveoli and the blood in the capillaries of the lung is, perhaps, not to be wholly explained by diffusion, some observers having found the tension of oxygen to be greater in arterial blood than in the alveoli of the lungs; this is the opposite of what we should expect as the result of simple diffusion. We may, however, assume that diffusion is the main factor in the exchange, which may perhaps be furthered by some peculiarity of the alveolar membrane which separates the air from the blood.

Blood plasma absorbs rather less oxygen than is taken up by water; blood, however, behaves very differently, for on being shaken with air it may absorb as much as 23 volumes per cent. of oxygen. That this large quantity is not held simply in solution is shown by subjecting arterial blood to an atmosphere in which the partial pressure of oxygen is gradually

reduced; under these circumstances, oxygen is slowly given up by the blood, as would be the case with water; but when the partial pressure of oxygen has been reduced to about 25 mm. of mercury, if the blood be at body-temperature, it begins to come off very rapidly, and the color of the blood changes from the arterial to the venous hue. The oxygen is for the most part held in loose **chemical combination with hemoglobin**, as oxyhemoglobin. One gram of hemoglobin, at 0° C. and 760 mm. Hg pressure, unites with 1.3 c.c. oxygen; it is contained in blood to the extent of about 14%. Arterial blood contains about 20 volumes per cent. oxygen, 40 volumes per cent. carbon dioxid, and 1 to 2 volumes per cent. nitrogen. The proportion of gases in venous blood is more variable; it contains, as a rule, 10 volumes per cent. oxygen, 47 volumes per cent. carbon dioxid, and 1 to 2 volumes per cent. nitrogen. It will be noticed that only a small proportion of the carbon dioxid is eliminated as the blood passes through the lungs, and that only about half the oxygen disappears from the arterial blood on its passage, from the arterioles to the veins, through the systemic capillaries.

Internal Respiration.—The cells of the various tissues prevent the accumulation of oxygen in the lymph which surrounds them; they display a great avidity for oxygen and take it up as fast as it reaches them, thus maintaining in the lymph a practical oxygen vacuum. Consequently, a rapid diffusion of oxygen must occur, through the capillary wall, from the plasma to the lymph; and as the partial pressure of oxygen diminishes in the plasma, the oxyhemoglobin of the red cells must, to a certain extent, be reduced. Oxygen will pass from the blood-cells to the plasma, and from the plasma into the lymph, thus reaching the tissue cells. The

individual capillaries are, however, so short that each red cell remains in this district but a brief period, and time is not given for the reduction of all its oxyhemoglobin ; still more is this the case when the arterioles of an active organ are dilated, and the blood flows through its capillaries with increased celerity. Under these circumstances a larger number of red cells will pass through each capillary in a given time, and though, in the aggregate, more oxygen will be given up to the lymph, each cell will part with a smaller quantity than usual, and the blood reaching the veins will retain its arterial color.

It is not to be supposed that the oxygen is, on reaching the cells of the various tissues, immediately combined with carbon to form carbon dioxid ; it seems rather to be stored within the cell in some more complex combination, which later on breaks down, with the liberation of carbon dioxid. Muscle, for example, may be caused to contract, and to perform a considerable amount of work, in the absence of free oxygen, giving off meanwhile carbon dioxid, which can only have originated by the break-down of some oxygen-containing substance, possibly of phosphocarnic acid, within the muscle.

The **carbon dioxid** thus formed by the cells passes into the lymph ; it accumulates here, and since the partial pressure of carbon dioxid is higher in the lymph than in the blood plasma, it diffuses from the former into the latter. Only a small proportion of the carbon dioxid carried in the venous blood is in simple solution, a rather larger proportion is in firm chemical combination, and the majority in loose chemical combination in the plasma ; a small quantity only is held in chemical combination in the corpuscles. On reaching the lungs

the carbon dioxid diffuses from the blood, where its partial pressure is high, into the air-spaces, where its partial pressure is low; as before stated, only about one-fifth of the carbon dioxid contained in venous blood is eliminated in this way. The setting free of carbon dioxid by the splitting-up of $NaHCO_3$, in which combination most of the CO_2 of the plasma is held, is brought about by the action of substances, oxyhemoglobin and globulins, which act as weak acids.

Nervous Control.—The respiratory muscles are under the control of the respiratory center, which is situated in the spinal bulb; in the neighborhood, therefore, of the important centers which govern the circulation. The respiratory center is bilateral, but the two halves, connected by commissural fibers, act in unison. It is **rhythmically active,** ordinarily at the rate of from fifteen to twenty respirations per minute, the respiratory rhythm usually varying with the heart rhythm as one to four. This center is exceedingly sensitive to nerve impulses which reach it from the periphery or from the higher centers in the brain, and to changes in the chemical composition of the blood. The nerve-fibers emanating from the respiratory center pass downward into the spinal cord without crossing the median line, and end, in the gray matter of the cord, in the neighborhood of the motor nerve-cells which, situated in the different regions of the cord, innervate the respiratory muscles. The center also dispatches impulses to the nuclei of some of the motor cranial nerves, and thus governs accessory respiratory movements which accompany inspiration, such as those of the vocal cords and alæ nasi. Although each half of the center controls the respiratory muscles situated on the same side of the body as itself, the nervous impulses which it discharges may, under certain circumstances, after de-

scending the cord, cross over to the opposite side and bring about the contraction of contralateral muscles. Destruction of the center puts an end to respiration and proves fatal. Division of the spinal cord just below the origin of the phrenic nerve causes paralysis of the thoracic and abdominal muscles concerned in respiration, but the diaphragm, innervated through the phrenic nerve, remains active. Division of the cord above the origin of the phrenic nerve proves as fatal as destruction of the respiratory center, though life may be supported for half an hour or so by the contractions of the sternocleidomastoids, innervated through the spinal accessory nerve.

Of the various stimuli to which the center is responsive, the condition of the blood is the most important. A **venous condition of the blood** acts as a strong stimulus to the respiratory center; consequently, it is impossible to voluntarily cease breathing for long at a time. It is easy to inhibit the center and prevent its response up to a certain point, but as the blood becomes more and more venous, the stimulation of the center grows so forcible that it overcomes our most strenuous efforts at inhibition, and we begin to breathe in spite of ourselves. If the blood is lacking in oxygen the inspiratory phase of respiration will be increased, and if there is an excess of carbon dioxid the expiratory phase will be increased, thus giving evidence that the bilateral respiratory center has an inspiratory and an expiratory portion which respond to appropriate stimulation.

Dyspnea, or difficult and labored breathing, may result from chemical or mechanical interference with a supply of blood to the respiratory center sufficient in quantity and with a sufficient degree of purity and oxygen content. Thus we may have hemorrhagic or

cardiac dyspnea, due to lack of bulk of blood, or force of blood sufficient to give a free circulation in the brain, or "O-dyspnea," due chiefly to a lack of oxygen, and "CO_2-dyspnea," due to an excess of carbon dioxid in the circulating blood. The center is also sensitive to changes in the temperature of the blood, a rise increasing, a fall lessening, its activity. As in the case of the cardio-augmentor center, the waste products of active muscular metabolism serve as a stimulus; exercise is accompanied by an increased rate and depth of respiration. Almost as important as the stimulus afforded by the lack of oxygen or excess of carbon dioxid is the influence exerted over the center by afferent nerve impulses. We may assume that the respiratory center, deprived of all stimuli, would cease to act; in other words, that it is **not spontaneously active.**

The respiratory center may be stimulated through almost any afferent nerve, those which, in relation to this center, are of most importance being the **afferent nerves of the respiratory tract.** Division of both vagi results in a lessened frequency and increased depth of respiration, owing to the absence of afferent impulses which, in the normal course of events, arising in the lungs and reaching the center through the vagi, in some way quicken its activity. The pulmonary terminations of these nerve-fibers seem to be stimulated either by the inflation or by the collapse of the lung, or by both. If, the vagi being intact, a sudden collapse of the lung be caused, there results a contraction of the diaphragm; if the lungs be suddenly inflated, the result is a relaxation of the diaphragm. One or other of these events is reflex; possibly both. Whether the impulses concerned are inhibitory to the respiratory center or result in its stimulation is uncertain.

The **inferior** or **recurrent laryngeal nerves** are pure motor nerves to the muscles of the larynx. The **superior laryngeal nerves** are motor for the cricothyroid muscle and sensory for the mucous membrance of the glottis and the larynx. Stimulation of the superior laryngeal nerves results in a cessation of respiration, followed, as a rule, by an expiratory effort, thus imitating the chain of events following the presence of an irritating gas or foreign substance at the entrance of the larynx; *i. e.*, holding the breath and then coughing. If the inferior laryngeal nerves are cut, the closure of the glottis and the explosive expiration do not occur, the apnea followed by expiratory effort being the only results of superior laryngeal nerve stimulation when the laryngeal muscles are paralyzed. Coughing may also result from irritation of the afferent fibers of the vagus in the lungs, stomach, or liver. **Sneezing** closely resembles coughing, save that part of the air is expelled through the nose, and may be excited by stimulation of the nasal branch of the fifth cranial nerve, or through the effect of a bright light on the retina. The reflex gasp which is excited by entering cold water is familiar to all. **During swallowing,** respiration is stopped by inhibition of the respiratory center through the glossopharyngeal nerve, the pharyngeal terminations of which are stimulated by the substance swallowed, thus affording a mechanism which prevents the inhalation of food into the trachea. The center may also be inhibited on the introduction of irritating gases into the nasal fossæ, the terminations of the fifth cranial nerve being thus stimulated; the same effect may be produced by the inhalation of liquid. As is well known, the emotions have a marked influence over the depth and rate of respiration, and may cause its temporary arrest. The

respiratory center is also under the control of the will, though it cannot be thus inhibited indefinitely.

When the proper arterialization of the blood is prevented, **hyperpnea**, or increased depth and frequency of respiration, ensues; if this does not result in the access of oxygen to the required extent, or in the removal of the surplus carbon dioxid, or both, there follows more exaggerated breathing, dyspnea, in which forcible expiration predominates. If the struggle still proves ineffectual, convulsions intervene, giving place to exhaustion, a few long-drawn inspirations, and death.

Apnea, or temporary cessation of breathing, may be induced by rapid artificial respiration; this, in the normal animal, is not due to overoxygenation of the blood, for the blood will take up little more oxygen than usual when pure oxygen is breathed, and the same condition is produced if hydrogen be used for inflating the lungs. It is caused by the effect produced on the respiratory center through the afferent fibers of the vagus, the pulmonary terminations of which are stimulated by the rapidly repeated distention and collapse of the lungs. If both vagi have previously been divided, it is more difficult to induce apnea, and impossible by the use of hydrogen; in this case, it is probably due to a better arterialization of the blood, which, after division of the vagi, has become defective.

QUESTIONS FOR CHAPTER III.

If a cannula which is connected with a mercury manometer be thrust through the chest-wall without injuring the lung, in which direction will the mercury move?

Under what circumstances will the movement of the mercury be greatest?

Is the interpleural pressure ever positive?

What force resists the expansion of the thorax when the glottis is closed?

Does the elasticity of the lungs aid in, or oppose, inspiration?

How is the color of the face affected by a fit of coughing, and what is the mechanism concerned?

Why is it impossible to voluntarily empty the lungs?

What force causes air to enter the lungs during inspiration?

Is it possible for a contraction of the diaphragm to cause expiration?

What would be the result of replacing the blood by serum?

What causes a newly born animal to breathe?

What causes the reduction of oxyhemoglobin in the systemic capillaries?

How is it that blood leaving an active organ may in color resemble arterial blood?

What are the direct and indirect effects of lack of oxygen?

Does the blood undergo purification on its passage through the heart?

Why is it dangerous to breathe coal-gas?

Is the color of venous blood due to the presence of an excess of carbon dioxid?

Give the causation and describe the occurrence of dyspnea.

The spectra of oxyhemoglobin and carbon monoxid hemoglobin are very similar. How can these two substances be most readily distinguished from each other?

Which of the effects of destroying the spinal bulb are immediately fatal?

What is the effect of separating the two halves of the medulla by a median incision?

Explain the result of introducing a foreign body into the larynx.

How is this effect modified after division of the spinal cord at the level of the seventh cervical nerves?

Of what importance is the stimulation of the medullary centers by the waste products of muscular activity?

How does biting the lip stop sneezing?

Why are the lungs less well protected after division of the glossopharyngeal nerves?

Why is it dangerous to divide the laryngeal nerves?

Curari paralyzes the skeletal muscles. How does it cause death?

Why is paralysis of the expiratory less injurious than that of the inspiratory muscles?

Why is ventilation necessary?

How does the contraction of the bronchial muscles affect respiration?

Why is the respiratory quotient of a herbivorous animal modified by starvation?

CHAPTER IV.

DIGESTION.

DIGESTION consists in the physical and chemical alteration of food, the resulting products being, as a rule, more easily absorbed, and in some cases more readily assimilated, than the food-stuffs as they are originally taken. In order that it may be absorbed, food must be **soluble,** though it is possible, but highly improbable, that fats form an exception to this rule.

Much of our food is taken in a form that requires **mechanical subdivision**; this is accomplished by the teeth and tongue, and by the movements of the stomach. The soluble portion of the food that happens to be taken in solid form—for instance, cane-sugar—is readily dissolved in the saliva or gastric juice, but insoluble food-stuffs must of necessity undergo some **change in composition,** and this is brought about by the various enzymes, or ferments, which are secreted by the glands of the alimentary canal, or by bacteria which are constantly present in the intestine.

Our food consists of a mixture of various substances, the most important of which are proteids, albuminoids, carbohydrates, fats, water, and inorganic salts. Proteids are essential, though taken alone they form neither a suitable nor economic diet. In discussing the digestion of these food-stuffs it will be well to treat them separately.

Digestion of Carbohydrates.—On introduction of the food into the mouth it is subjected to the

influence of the **saliva**, with which it is mixed by movements of the tongue and lower jaw. Here begins the solution of those food-stuffs which are soluble in water. That part of digestion which consists of chemical change also begins in the case of cooked starch and the dextrins. Uncooked starch is insoluble; it exists in the form of granules covered with envelopes of cellulose, which is also insoluble, and which, though it belongs to the starch group of carbohydrates, is not attacked by the enzymes of the alimentary canal; it passes unchanged through the mouth and stomach into the intestine, where a part of it is acted on by bacteria. The cooking of starch breaks open the cellulose envelopes, and the starch, rendered partly soluble, is set free. There is contained in saliva an enzyme, **ptyalin**, which is manufactured by the salivary glands, and which is **amylolytic**; that is, it brings about the hydrolysis of starch. By this ferment starch is converted into soluble starch or amylodextrin. The soluble starch is further split up into dextrin and malt-sugar; the dextrin thus formed also undergoes hydrolysis, being converted into a simpler form of dextrin and maltose. The final product is maltose, but before the series of reactions ends there probably are a number of different dextrins formed; each one, in turn, being split up with the formation of a simpler dextrin and malt-sugar. The formula $(C_6H_{10}O_5)_n$ is used to represent each member of the starch group. Supposing, for the sake of simplicity, that the true formula for soluble starch is $(C_6H_{10}O_5)_{30}$, as has been stated, then the series of changes which occur may be represented by the following equations:

$$(1)\quad \underset{\text{Sol. Starch}}{(C_6H_{10}O_5)_{30}} + H_2O = \underset{\text{Dextrin}}{(C_6H_{10}O_5)_{28}} + \underset{\text{Maltose}}{C_{12}H_{22}O_{11}}.$$

$$(2)\quad \underset{\text{Dextrin}}{(C_6H_{10}O_5)_{28}} + H_2O = \underset{\text{Dextrin}}{(C_6H_{10}O_5)_{26}} + \underset{\text{Maltose}}{C_{12}H_{22}O_{11}}.$$

$$(3)\quad \underset{\text{Dextrin}}{(C_6H_{10}O_5)_{26}} + H_2O = \underset{\text{Dextrin}}{(C_6H_{10}O_5)_{24}} + \underset{\text{Maltose}}{C_{12}H_{22}O_{11}}.$$

and so on to the last of the series:

$$(15)\quad \underset{\text{Dextrin}}{(C_6H_{10}O_5)_2} + H_2O = \underset{\text{Maltose}}{C_{12}H_{22}O_{11}}.$$

According to some observers, another form of sugar, isomaltose, appears during the hydrolysis of starch, but is converted into maltose. We can distinguish two varieties of dextrin by their behavior with iodin: erythrodextrin gives with iodin a red color reaction, which disappears on heating and reappears on cooling; achroodextrin is so called because it gives no color reaction on treatment with iodin. Starch gives a dark blue color with iodin. Ptyalin is sensitive to a change in reaction; it acts best in neutral or slightly alkaline solution, and its action is prevented by the presence of a trace of free mineral acid. The gastric juice contains hydrochloric acid, but at the beginning of digestion this is combined with the proteids that enter the stomach, and in this condition does not prevent the action of ptyalin, though it reddens litmus. Saliva that is swallowed and enters the stomach may, therefore, continue to act upon starch and dextrins for half an hour or more, after the beginning of a meal, until there is a surplus of HCl which is uncombined with proteid; when this occurs, the action of pytalin must cease. That portion of the starch and dextrins which is not digested by saliva, either in the mouth or stomach, passes into the intestine. The **pancreatic juice** contains an enzyme, **amylopsin,** which closely resembles pytalin in its action, and may be identical with it. Not only does the amylopsin convert the dextrins and cooked starch which may have escaped salivary digestion into maltose, but it also brings about the same changes in

any raw starch that has been liberated from its cellulose covering through the action of bacteria. Probably none of the starch or dextrin which enters the intestine is absorbed before undergoing digestion, for amylopsin acts rapidly and powerfully, but it is possible for both these substances to be absorbed as such in the large intestine. So far, then, we have found that starch is converted by digestion into maltose, a sugar which, although capable of being absorbed, is of no value as such to the organism; if it enters the blood as maltose, it is excreted by the kidneys. Yet it is very unusual to find maltose in the urine, for the maltose which happens to be absorbed by the epithelial cells which line the stomach and intestines is converted, before it reaches the blood, probably by the action of an enzyme contained within the cells, into dextrose. This change also occurs within the stomach under the influence of hydrochloric acid, one molecule of maltose being, by hydrolysis, converted into two molecules of dextrose. The succus entericus, or intestinal juice, contains an enzyme, **invertin**, which brings about the same change. **Cane-sugar** is acted on by neither pytalin nor amylopsin; like maltose, it is of no value to the body until it has been digested, though it may be absorbed. After eating very large quantities of cane-sugar a very small amount may be found in the urine, but the majority is hydrolyzed before or during absorption; the change occurs either in the stomach through the action of hydrochloric acid, in the intestines under the influence of invertin, or during its passage through the epithelial cells. The nature of the change is as follows:

$$\underset{\text{Cane-sugar}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Levulose}}{C_6H_{12}O_6}.$$

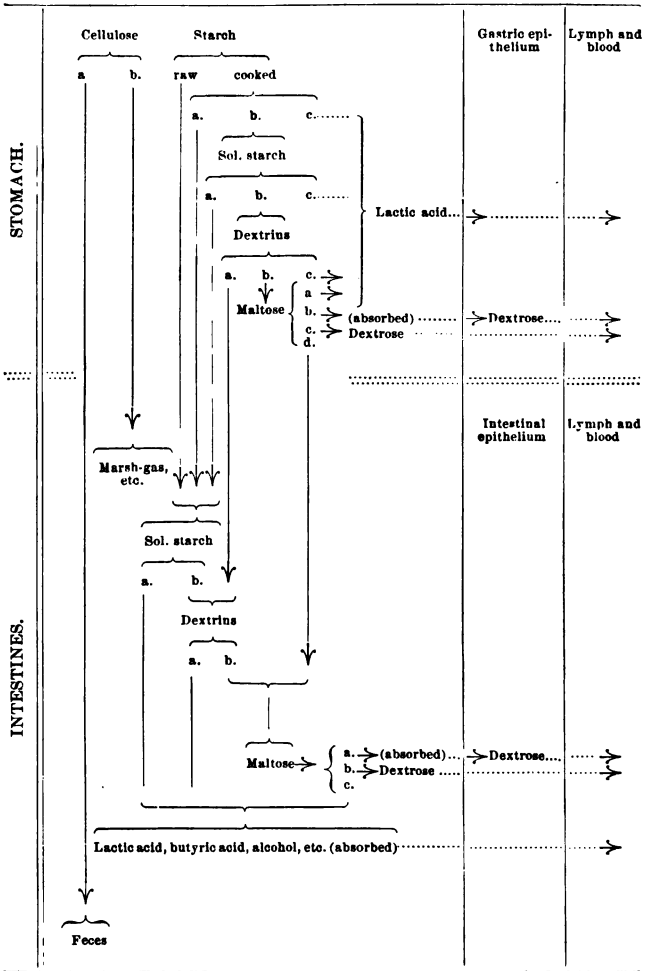
Both dextrose and levulose are assimilable; that is, they can be utilized by the bioplasm. **Lactose**, or milk-

sugar, is another disaccharid which is acted on in the same way in the intestine, but not in the stomach; the change is as follows:

$$\underset{\text{Milk-sugar}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Galactose}}{C_6H_{12}O_6}.$$

Not all the dextrose which is taken with the food or is formed during digestion reaches the blood; a variable quantity becomes the prey of **bacteria.** This may occur in the mouth, if the sugar is retained between the teeth; in the stomach, during the period when there is no free hydrochloric acid present; or in the intestines, which constantly contain bacteria. The main result of this bacterial decomposition is the formation of **lactic acid.** The lactic acid bacillus not only acts on sugar, but attacks starch and the dextrins also, probably first converting these into dextrose, and the dextrose into lactic acid. The destruction of the enamel of the teeth is due to the formation of lactic acid in this way. The lactic acid may be partly converted into butyric acid by the further action of bacteria. Another product of the decomposition of carbohydrates by bacteria in the intestines is alcohol, which is formed in small quantities only. This is, of course, absorbed together with the lactic acid, and oxidized in the system. The **succus entericus,** or intestinal juice, which is secreted by the simple glands of the intestinal mucous membrane, exerts a very feeble diastatic action, slowly converting starch into sugar; it also inverts cane-sugar into dextrose and levulose; converts maltose into dextrose, and lactose into dextrose and galactose. Much of the cellulose escapes bacterial decomposition and appears in the feces. The starch and dextrins which on introduction into the large intestine may be absorbed without previous change are evidently digested on their way through the epithelium, for they do not appear in the blood.

TABLE 3.—DIGESTION OF STARCH.



In Table 3 the double dotted line represents the pylorus; above these lines are shown the changes undergone by starch and its products in the stomach, the change beginning, however, in the mouth. Below these lines are given the changes which occur in the intestines. The different agencies through which these reactions are effected are mentioned above, in the text.

Digestion of Proteids.—Proceeding to the digestion of another group of food-stuffs, namely, the proteids, we have to do with substances the majority of which are more complex than even starch. Of their structural formulæ we have no knowledge. As their name indicates, they are the most important of the food-stuffs, without a supply of which life cannot be supported for any considerable time. Their chief characteristics have been already mentioned.

Uncooked proteids and those which are not rendered insoluble by heat may, if given in the solid form, be dissolved in the saliva. Saliva, however, contains no proteolytic enzyme; it is incapable of bringing about any chemical change in the proteids, which, consequently, suffer no digestion before they reach the stomach, though they may, if long retained within the mouth,—for instance, between the teeth,—undergo bacterial decomposition. Although, like soluble starch, the soluble native proteids may, to a certain extent, be absorbed from the intestine without first undergoing digestion, the absorption of the products of proteid digestion goes on much more rapidly; coagulated proteids are altogether incapable of being absorbed until they have been converted into a soluble form. Our knowledge of the changes which proteids undergo during digestion is even less exact than in the case of carbohydrates, but it seems highly probable that here, too, we have a series of hydrolytic reactions, the original mole-

cule of native proteid being hydrated and split up into simpler and more stable substances. In support of this view it may be mentioned that the same products result from the treatment of proteids with hydrolyzing agents, such as boiling mineral acids or superheated steam.

On entering the stomach, proteids are subjected to the influence of the **gastric juice**, the important constituents of which are pepsin, hydrochloric acid 0.2%, rennin, water, and inorganic salts.

The first recognizable step in the digestion of the native proteids is their conversion into a form which, unless first precipitated by neutralization, is uncoagulable by heat. For example, egg-albumen is converted by **pepsin** (the proteolytic enzyme of gastric juice) and **hydrochloric acid**, or more slowly by the action of hydrochloric acid alone, into an **albuminate**—acid albumin. If a digestion which contains albuminate be neutralized, a precipitate is formed which consists of albuminate, and is called a neutralization precipitate; if an excess of alkali be added, the albuminate redissolves, as an alkali albumin. Albumin that has been coagulated by boiling is by pepsin and hydrochloric acid converted into soluble albuminate, but the change is less rapid than in the case of soluble albumins. All the native proteids may be acted on in this way. As gastric digestion progresses, the albuminates are converted into **proteoses**, and these into **peptones.** The solubility of the proteid increases as it passes from one form to the next; at the same time, its power of diffusing through animal membranes increases. Native proteids and albuminates are nondialyzable; proteoses are very slightly dialyzable, peptones distinctly so, though they pass through membranes much more slowly than do the simpler crystalloids. This probably depends upon the large size of the proteid molecule.

Pepsin is incapable of causing proteolysis in neutral or alkaline solution; it requires the presence of an acid, hydrochloric acid being the most favorable to its action. It is quickly destroyed by alkalies, and acts less rapidly when neutral salts, such as sodium chlorid, are present.

Peptones are the final products of gastric digestion, but they may undergo further change on reaching the intestines, where they are acted on by the **pancreatic juice.** The pancreas secretes a proteolytic enzyme, **trypsin,** the action of which is very similar to that of pepsin. Unlike pepsin, it is destroyed by hydrochloric acid, though weak organic acids do not prevent its action; it acts best in alkaline solution, the optimum degree of alkalinity being that of 1% sodium carbonate; it may act in neutral solution. It possesses the power of splitting a portion of the peptones into simpler bodies, known as **amido-acids,** such as leucin, tyrosin, and aspartic acid; these are not proteids. Only half the peptones formed by the gastric digestion of a given quantity of proteid can be converted by trypsin into amido-acids. Whether the peptones formed by the action of pepsin are of two distinct varieties is uncertain; it has been supposed that albuminate is split into two forms of albumose, called hemi-albumose and anti-albumose, and that these are converted into different forms of peptone; in the one case hemipeptone, in the other, antipeptone; the final product of gastric digestion being a mixture of these two peptones, called amphopeptones. If amphopeptones be subjected to the action of trypsin, the hemipeptone is converted into amido-acids, leaving antipeptone unchanged. This theory is known as the cleavage theory of proteid digestion. Be this as it may, it is perfectly true that more than one form of albumose appears when pepsin acts on albuminate. Albuminate is split up

into proto-albumose and hetero-albumose, but as neither of these can be converted entirely into amido-acids, neither can be called hemi-albumose; neither entirely resists conversion into amido-acids, so neither can be pure anti-albumose. Both proto-albumose and hetero-albumose are changed by pepsin into deutero-albumoses, which differ slightly from one another in solubility; these are converted into amphopeptones. Trypsin converts proteids into peptones much more rapidly than does pepsin, and the intermediate products seem to be less numerous, no proto-albumose and no hetero-albumose having been found in artificial pancreatic digestions. The albumin is, as in gastric digestion, changed to albuminate, this time alkali albumin; the albuminate is, in turn, changed to deutero-albumoses, and the digestion of these last results in antipeptones and amido-acids. Possibly the deutero-albumoses are split directly into peptone and amido-acid moieties; this, at least, is the simplest way of expressing the result. Pancreatic juice obtained from a fasting animal possesses no proteolytic power.

The native proteids, albumins, and globulins are all digested by both pepsin and trypsin, and pass through the same stages; in the case of the globulins, the third stage is that of globulose. The globuloses may be grouped with the albumoses under the head of proteoses. The solubility of these different proteids is given in Table 1, page 14.

With regard to the amount of amido-acids formed in normal intestinal digestion, observers differ. According to some, very little leucin or tyrosin appears, the proteoses and peptones being absorbed about as fast as they are formed; according to others, a considerable percentage of the peptones is normally changed to amido-acids.

The **succus entericus** contains no proteolytic enzyme, and, consequently, takes no part in the digestion of proteids; its enzymic action being confined to that which it exercises on the disaccharids and starch.

There are present in the intestine **bacteria** which cause the putrefaction of proteids: this occurs only to a slight extent in the small intestine, but in the large to a considerable degree. As long as carbohydrates are present the action of bacteria seems to be exerted on them only, the proteids being spared. The nature of this bacterial decomposition of proteids is, in the early stages, very similar to that resulting from the action of pepsin and trypsin; there are formed proteoses, peptones, and tyrosin. In addition, however, there appear indol, skatol, phenol, and parakresol, the two latter being formed from tyrosin; hydrogen and hydrogen sulphid are also set free. The indol, skatol, etc., are, for the most part, excreted with the feces, and are answerable for the fecal odor; to a certain extent, however, they are absorbed, and carried in the portal blood to the liver. These substances are poisonous if administered in any but small quantities. The amount absorbed from the intestines is small, and exerts no poisonous action, for, in the liver, a chemical union between each of these substances and a sulphate is brought about, the resulting compound—for example, potassium-phenyl-sulphate—being harmless; these **conjugated sulphates** are excreted by the kidneys.

The pancreatic digestion of proteids seems to be favored by the presence of **bile**; at least, this is the case when artificial pancreatic digestion is carried on outside the body, 20% more peptones being formed in a given time. Bile is a weak antiseptic, and probably controls to a certain extent the growth and activity of the intestinal bacteria. It would appear that no

ptomains are formed in the intestine, though bacteria capable of forming them are present; were they formed, we might expect ptomain poisoning to follow every proteid meal. Bacteria, of course, enter the stomach, and, as has been stated, bring about lactic acid fermentation; as soon, however, as hydrochloric acid, the proteids being saturated, appears in the free state, the activity of bacteria ceases. The hydrochloric acid of the gastric juice also affords a certain amount of protection against pathogenic bacteria; the cholera bacillus is destroyed by it, but, unfortunately, this is not the case with the tubercle bacillus.

The native proteids are not all digested with the same ease; animal proteids are, as a rule, more readily digested than those found in vegetables. An **indigestible residue** has, nevertheless, a value, for without it the peristaltic movements of the intestines are not so vigorous, a milk diet often leading, for this reason, to constipation. The cellulose of vegetables to a great extent escapes digestion, and affords a mechanical stimulus to the intestinal walls. Proteids which have been coagulated by cooking are less readily digested than when raw, as is markedly the case with egg-albumen.

Our food contains considerable quantities of **nucleoproteid**, and this during gastric or pancreatic digestion is split up in the first place into proteid and nuclein. The proteid moiety is digested in the ordinary manner and converted into peptones, etc., but nuclein is almost indigestible; it escapes gastric digestion altogether, is but little affected by the pancreatic juice, and is for the most part excreted with the feces.

Nucleo-albumins differ from nucleoproteids in that they are compounds of proteid with pseudonuclein, the latter yielding, on decomposition, no xanthin bases.

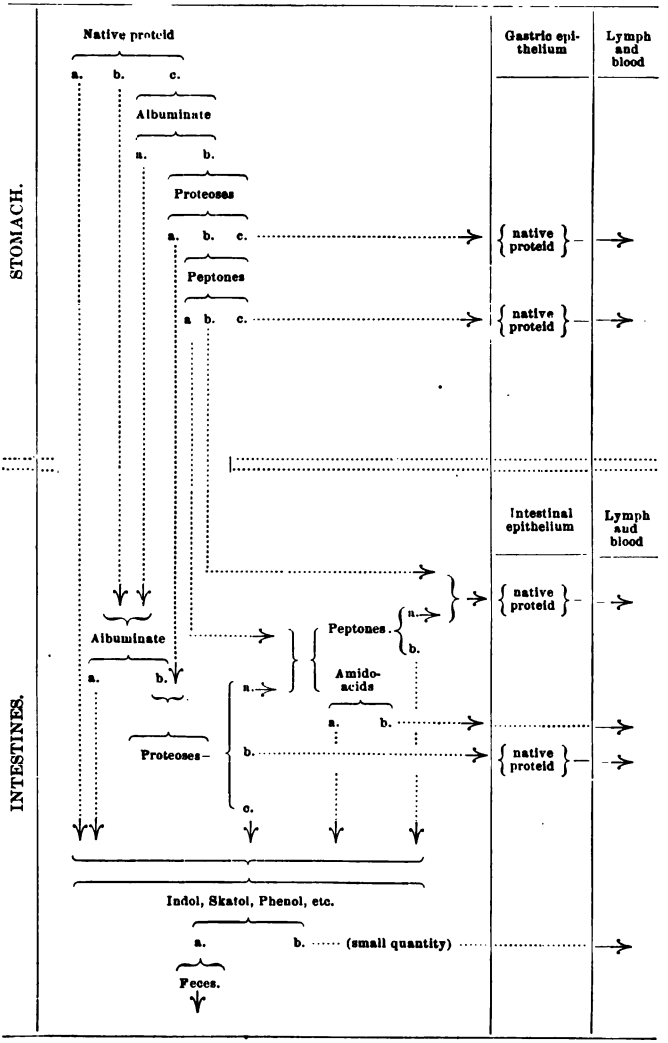
The most familiar nucleo-albumin is **caseinogen**, the chief nitrogenous constituent of milk. The curdling of milk which occurs in the stomach is due to the coagulation of this substance by the **rennin** of gastric juice. The curdling of milk which occurs outside the body is due to the precipitation of caseinogen by lactic acid, formed by fermentation of milk-sugar; the curd thus formed differs chemically from that produced by rennin. Rennin is an enzyme which acts in neutral, slightly acid, and slightly alkaline solutions. Under the influence of rennin, caseinogen is split up, probably through hydrolysis, into soluble casein, and whey proteid which is also soluble. If soluble calcium salts be present, the soluble casein unites with calcium to form calcium caseate, which is insoluble and constitutes the curd. The curd then contracts and expresses the whey, but retains the fat within it. The whey proteid is readily digested by either pepsin or trypsin, and is converted into peptones. The first step in the digestion of the insoluble casein, calcium caseate, or curd, consists in splitting off proteid, the pseudonuclein remaining as an insoluble precipitate. The proteid thus set free is digested by pepsin and hydrochloric acid, and carried through the proteose stage of caseose, to peptones. Boiling milk renders it rather less readily digestible; in the case of cow's milk, however, this effect is somewhat neutralized by the fact that in this condition it curdles in small flocculi instead of in large masses, so that it is more thoroughly exposed to the action of the gastric juice. In this respect human milk behaves like boiled cow's milk. The dilution of milk accomplishes the same result.

A group of substances known as **albuminoids**, from the fact that they possess many of the characteristics of albumin, forms another important division of food-stuffs;

amongst them we find collagen and its hydrate gelatin, elastin, keratin, chondrin, and ossein, the two latter being impure forms of collagen. They are for the most part less readily digested than proteids; keratin, for instance, being altogether indigestible. Keratin is a horny substance found in hair and nails, and in the horny layer of the epidermis. Elastin may be slowly digested by pepsin or trypsin, the resulting products being elastoses resembling the proteoses. Collagen is found in white fibrous connective tissue and in bone and cartilage; it is converted by boiling or by the action of the gastric juice into gelatin. Gelatin is insoluble in cold water, but may be readily dissolved in hot; prolonged boiling destroys its power of gelatinizing on cooling. It is digested by pepsin or trypsin, and converted into gelatoses and peptones; these are, however, not true proteid peptones. Although the percentage composition of gelatin very closely resembles that of proteid, that there are important differences between them is shown by the fact that gelatin cannot altogether replace the proteids of our food, though it can better do so than either fat or carbohydrate. Gelatin cannot be built up into the proteid of bioplasm, it is simply used by the cell as fuel; it cannot even be stored up as collagen, for the albuminoids of the body are all formed from proteid.

We have seen that proteids, compound proteids, and some of the albuminoids are during digestion converted into proteoses and peptones, which may be absorbed; yet, if introduced into the circulation, proteoses and peptones act as poisons, producing a marked fall of arterial blood pressure, and narcosis; they also cause a temporary loss of coagulability on the part of the blood. If commercial peptones be injected into the blood-vessels of a dog to the extent of $\frac{1}{3500}$ of its body-weight, the dose proves fatal. Yet after every proteid meal these poisonous substances

TABLE 4.—DIGESTION OF ALBUMINS AND GLOBULINS.



are absorbed in quantity by the epithelial cells which line the intestines. Peptones are, however, not found in the blood under ordinary circumstances, and if they reach the blood, are at once excreted (provided the blood pressure is not too much depressed) by the kidneys. It appears that the epithelial cells, having taken up the peptones, reconvert them by synthesis into native proteids, and discharge them in this condition into the lymph, from which they pass into the blood-capillaries. The work done by the digestive juices might, at first sight, appear to be labor spent in vain, for the peptones so formed must be reconverted into albumins or globulins by the epithelial cells, and this entails the expenditure of a large amount of energy; further, it has been shown that soluble native proteids may be absorbed without undergoing digestion. We must, however, remember that peptones are more readily absorbed than undigested proteids, and that coagulated proteids are incapable of absorption until they have been rendered soluble by digestion. Again, gelatin, egg-albumen, casein, and several other forms of soluble proteids are nonassimilable, and if injected directly into the circulation are excreted by the kidneys. These substances must undergo some change in constitution before they can be utilized as food by the cells of the body. The epithelial cells which line the intestines evidently possess the power of bringing about this rearrangement of the molecule of egg-albumen, provided it has not been rendered insoluble by cooking, but it is possible that the change is more readily effected after digestion has occurred; it may be easier for the epithelial cell to construct serum albumin out of egg-albumen peptones than out of the native unchanged egg-albumen.

The gastric digestion of proteids is, on the whole, favored by the use of small quantities of **alcohol.** It is

true that the presence of alcohol somewhat retards the action of pepsin, but alcohol taken in small quantities is rapidly absorbed from the stomach. It stimulates the gastric glands to more rapid secretion of the gastric juice, and in this way, at least in cases where the process is less active than normal, hastens digestion.

Not all the proteid of the food is digested and absorbed; a variable amount, especially of the vegetable proteid, is excreted with the feces.

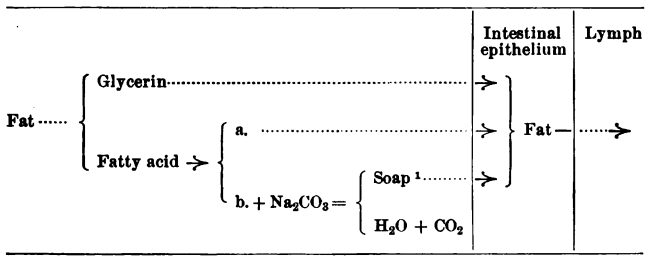
Digestion of Fat.—Fats are digested neither in the mouth nor in the stomach, but in the latter may, to a small extent, undergo bacterial decomposition. In the intestine they are emulsified. Fats which contain some free fatty acid may be emulsified by the soap which is formed by the union of this fatty acid with sodium, the latter being derived from the sodium carbonate of the pancreatic juice and bile. Neutral fats, which contain no free fatty acid, are also emulsified in the intestine, but not quite so readily, for in this case, before emulsification can take place, some of the fat must be split up with the liberation of fatty acid, which, with sodium, forms soap. The splitting of the fat is caused by an enzyme of the pancreatic juice, called **steapsin**, or pialyn. The change produced is hydrolytic, one molecule of fat being hydrated and split up with the formation of one molecule of glycerin and three molecules of fatty acid; for example:

$$\underset{\text{Stearin}}{C_3H_5(C_{18}H_{35}O_2)_3} + 3H_2O = \underset{\text{Glycerin}}{C_3H_5(OH)_3} + 3\underset{\text{Stearic Acid}}{C_{17}H_{35}CO_2H}.$$

It is probable that all the fat which is absorbed is first split up in this way; some of the fatty acid set free is combined as soap, and by emulsifying the rest of the fat, hastens its digestion, for in this way the fat is more completely exposed to the action of the steapsin; an-

other portion is probably absorbed by the epithelium as fatty acid. Fatty acids are insoluble in water, but in the intestine they are held in solution by the presence of **bile salts**, sodium glycocholate and sodium taurocholate: the favorable influence exerted by bile on the digestion of fat probably depends on this property. Some of the fatty acid may be absorbed as soap. It is highly improbable that fat is absorbed without undergoing digestion, as has been supposed. The fatty acid which is absorbed is, by the epithelial cells, recombined with glycerin to form fat; the absorbed soap is combined in the same way, the sodium being first split off and united with some other acid radicle. Even if fatty acid be administered in the absence of glycerin, it may be converted into fat in the epithelial cells, which in this case appear to manufacture the glycerin. In the absence of bile, the absorption of fat is defective, much of it undergoing bacterial decomposition into fatty acids in the large intestine and being excreted in the feces.

TABLE 5.—DIGESTION OF FAT IN THE INTESTINE.



The fat which passes from the intestinal epithelial cells into the lymph-spaces of the villi does not enter

[1] The soap first formed causes the emulsification of the remaining fat.

the blood-capillaries, but passes through the lymphatic vessels into the thoracic duct, and so reaches the subclavian vein, where it is mixed with the blood. The soluble constituents of the food, on the other hand, pass from the lymph-spaces of the villi into the blood-capillaries, for the percentage of sugar and proteids in the lymph which reaches the thoracic duct is very little increased during absorption. Sugars and proteids may be absorbed in the stomach to a certain extent, but in the intestine conditions are much more favorable to absorption. Water is not absorbed from the stomach, but passes on into the intestines; it is absorbed most rapidly in the ileum and large intestine.

Bile.—The chief constituents of bile, as secreted by the liver, are water, bile salts, inorganic salts, pigments, cholesterin, lecithin, and soaps. To these, as the bile passes through the ducts, and during its stay within the gall-bladder, is added mucin. The bile salts are sodium glycocholate and sodium taurocholate; in human bile the former predominates. They are present in bile to the extent of about 7.5 %. They are largely reabsorbed, but in the intestine a portion of these salts may be hydrolyzed through the action of bacteria, as follows:

$$\underset{\text{Glycocholic Acid}}{C_{26}H_{43}O_6} + H_2O = \underset{\text{Cholic Acid}}{C_{24}H_{40}O_5} + \underset{\text{Glycocol}}{CH_2.NH_2.CO_2H}$$

$$\underset{\text{Taurocholic Acid}}{C_{26}H_{43}O_6} + H_2O = \underset{\text{Cholic Acid}}{C_{24}H_{40}O_5} + \underset{\text{Taurin}}{C_2H_4NH_2SO_2OH}$$

The taurin, glycocol, and part of the cholic acid formed are absorbed. The bile salts are useful in holding in solution cholesterin and lecithin, and appear to be used more than once, possibly over and over again. It has already been mentioned that they exert an important influence on the absorption of fat. The **bile pigments**, bilirubin and biliverdin, originate from the hemoglobin,

of broken-down red blood-cells; they contain, however, no iron, this being split off and retained in the liver, where the bile pigments are formed. The iron so retained may be used in the synthesis of new hemoglobin. A certain amount of bile pigment seems to be reabsorbed from the intestine, to be again excreted. Most of the pigment is reduced by the action of the free hydrogen in the intestine, or, through putrefaction, to hydrobilirubin, some of which is absorbed and eliminated by the kidneys; in the urine it is called **urobilin.**

Movements Concerned in Digestion.—Secretion of the Digestive Juices.—Mastication is performed by movements of the lower jaw, the muscles concerned being innervated through the inferior maxillary branch of the fifth cranial nerve. The food is kept between the teeth by movements of the tongue and contraction of the muscles of the cheeks. The food is thus not only ground up, but is mixed with the **saliva.** The latter is secreted by three pairs of glands, the parotid, submaxillary, and sublingual glands; and to a smaller extent by the glands of the oral mucous membrane. The activity of the salivary glands is controlled by the central nervous system, the salivary centers being situated in the spinal bulb. Two sets of secretory nerves, cranial and sympathetic, are distributed to each gland. The cranial nerve-fibers (pre-ganglionic) which innervate the parotid leave the bulb in the ninth cranial nerve and probably end in the otic ganglion in contact relations with nerve-cells whose axons (post-ganglionic) reach the parotid through the auriculotemporal branch of the trifacial. The cranial fibers which control the submaxillary and sublingual glands emerge from the bulb in the facial nerve, and, by way of the chorda tympani, reach the submaxillary and sublingual ganglia.

In these ganglia they end, and make physiologic connection with cells whose post-ganglionic fibers are distributed to the gland-cells. Post-ganglionic sympathetic nerve-fibers from the superior cervical sympathetic ganglion are supplied to each of these glands. The cranial secretory fibers are accompanied by vasodilator fibers; the sympathetic, by vasoconstrictors.

Artificial stimulation of the **chorda tympani** produces a result which differs widely from the effect of stimulating the **cervical sympathetic.** In the former case, the submaxillary gland secretes abundant watery saliva; in the latter case, the secretion is thick and scanty. Stimulation of the chorda tympani of course increases the blood supply of the gland, and thus renders a copious secretion possible, but the variation of the blood supply probably does not account altogether for the difference in the two results. The normal secretion of saliva is a **reflex** event. It is readily initiated by stimulation of the terminations of the afferent nerves of the oral mucous membrane by food or other substances placed in the mouth, weak acids forming a particularly effective stimulus. Reflex secretion of saliva is not brought about through the sympathetic nerve-fibers, but only through the cranial fibers. The salivary centers are not under the control of the will, but by thinking of food we may cause the dispatch of involuntary nerve impulses from the brain to the salivary centers, and thus indirectly bring about a flow of saliva. These centers may be not only excited through the emotions, as by the sight or smell of food, but they may also be inhibited, as by fear or nervous worry. Reflex secretion of saliva may result from stimulation of afferent nerves in parts of the body other than the mouth; irritation of the gastric mucous membrane may cause it, a flow of saliva usually pre-

ceding vomiting. Irritation of the uterus may also be effective, the early stages of pregnancy often being accompanied by profuse secretion of saliva. After division of the chorda tympani there follows a slow continuous secretion of saliva by the submaxillary gland; this is called **paralytic secretion**, and probably results from a local stimulation of the group of nerve-cells in the gland which form the submaxillary ganglion. How the stimulus originates is unknown, and it may be that the activity of the nerve-cells is increased by the cessation of inhibitory impulses, which normally are perhaps transmitted to them through the chorda tympani. The administration of **atropin** causes dryness of the mouth, by paralyzing the terminations of the post-ganglionic fibers of the cranial nerve supply; the sympathetic fibers are not affected. **Pilocarpin** provokes secretion, apparently by stimulating the terminations of the same fibers.

The food, after being masticated and mixed with the saliva, is **swallowed**. Only the first of the movements which play a part in deglutition are voluntary. If the mouth be empty of anything that could be swallowed, including saliva, it is impossible to voluntarily provoke all the swallowing movements. They are for the most part purely **reflex**, and are excited through the afferent nerves of the soft palate, of the back of the tongue, and of the fauces, which are stimulated by the contact of food, or any other substance, with the mucous membrane covering these parts. The first part of the action, which may be accomplished voluntarily, consists in the approximation of the tip of the tongue to the hard palate, followed by a raising of the floor of the mouth and tongue by the contraction of the mylo-hyoid muscles. This forces the food back through the fauces into the pharynx; in the case of liquid no further

muscular action is necessary to carry it as far as the lower end of the esophagus; nevertheless, the contraction of several muscles, in regular sequence, follows. As the food enters the pharynx, it is prevented from passing upward into the nasal pharynx by the contraction of the levatores palati and superior constrictors of the pharynx, which occurs even before the food touches the soft palate; its entrance into the larynx is prevented both by the contraction of the arytenoid muscle, which pulls the posterior border of the opening of the larynx forward, and by the thyrohyoid muscles, which raise the larynx. At the same time the glottis is closed, and the respiratory center inhibited through the glossopharyngeal nerve. The downward passage of solid food is furthered by the contraction of the constrictors of the pharynx and the esophageal muscles; these also contract on the deglutition of liquid, though their assistance seems to be unnecessary. If successive mouthfuls of liquid be swallowed, the esophageal muscles and cardiac sphincter are inhibited and remain lax. The center (or centers) controlling deglutition is situated in the spinal bulb; the afferent nerves concerned in the reflex are the fifth and ninth cranial nerves and the superior laryngeal branch of the tenth; the artificial stimulation of this latter nerve may cause swallowing movements when the pharynx is empty.

The entrance of food into the stomach is followed by **secretion of gastric juice,** flushing of the mucous membrane, and muscular **movements of the stomach-wall.** These events may also be induced by the taking of food into the mouth, or even by the sight of food. The efferent nerve concerned in the reflex secretion of gastric juice is the vagus, but after division of both vagi, secretion still occurs on the introduction of food into the stomach; in this case it may be controlled by nerve-cells

situated in the walls of the stomach itself. The effect produced by the introduction of food varies considerably with the nature of the food; mere mechanical stimulation causes but a scanty secretion, while peptones are particularly effective; they perhaps stimulate the gland cells or local nerve-cells after absorption. The vagus also contains visceromotor nerve-fibers for the stomach; the sympathetic may supply a few motor fibers, but the usual effect of stimulating this nerve is the inhibition of gastric movements. After division of all the nerves received by the stomach, and even after its removal from the body, its contractions may continue in normal sequence; this must be due either to the action of a local nervous mechanism, or to the nature of the muscle itself. The movements which occur on the introduction of food are at first feeble, but increase in force as digestion proceeds. The contractions of the pyloric end are the more marked, and are peristaltic; the contractions of the cardiac end, or fundus, being tonic. The peristaltic movements of the pyloric end, or antrum, serve to keep the food in motion, and to press the already digested portion through the pylorus, which relaxes at intervals. The vagus also transmits to the stomach inhibitory nerve-fibers; it is perhaps through these that its movements are lessened by disagreeable emotions. The entrance of food into the stomach provokes not only a reflex secretion of gastric juice, but of **pancreatic juice** also, the efferent secretory nerve being in each case the vagus. Therefore when the first portion of the chyme passes into the duodenum, pancreatic juice will have begun to accumulate here. The **secretion of bile** is also hastened by the introduction of food into the stomach, but this accumulates in the gall-bladder, and does not enter the duodenum until a reflex contraction of the gall-bladder is instituted by the stimulation of the duo-

denal mucous membrane caused by the acid chyme. The chyme then will be mixed with, and neutralized by, the alkaline bile and pancreatic juice; the pepsin will be rapidly destroyed by the trypsin and sodium carbonate, and the partly digested proteids precipitated by the bile salts. The secretion of pancreatic juice is not entirely dependent on the central nervous system; there exist local ganglia which govern the activity of this gland. The secretion of bile seems to be influenced more or less by the absorbed products of gastric digestion. During starvation the **intestines** are pale and motionless, but after the taking of food they become flushed with blood and exhibit movements of two kinds, **rhythmic** and **peristaltic.** The rhythmic or pendular movement consists of a swaying of the intestinal loops occasioned by the contraction of both the longitudinal and circular coats of muscle, constriction being but little in evidence. The wave of contraction passes over the intestines, from above downward, from twenty to fifty times as rapidly as the peristaltic contractions. The rhythmic movements are of muscular, the peristaltic of nervous, origin. As in the case of the stomach, the vagus supplies the intestine with both motor and inhibitory nerve-fibers; the sympathetic supplies chiefly inhibitory fibers. These nerves appear, however, to exert only a regulatory influence over the intestinal movements, for after the division of all the extrinsic nerves, peristalsis may continue or become exaggerated; the nerve-cells of Auerbach's plexus probably constitute a local mechanism by which peristalsis is coordinated. The movement consists of a constriction which travels from the duodenum downward at the rate of about 1 mm. per second, and is preceded by a wave of relaxation; the latter, of course, increases the ease with which the contents of the intestine are pressed onward by the constriction following in its wake. If a

local stimulus be applied to the mucous membrane of the intestine, a constriction appears above the point stimulated, while for some distance below, the muscles are inhibited and relax.

The **large intestine** shows similar peristaltic movements, which begin at the ileocecal valve, and are propagated in the direction of the rectum, but do not reach it. The feces accumulate in the sigmoid flexure. The descending colon, rectum, and anus receive two sets of nerve-fibers, one, coming through the sympathetic, from the lumbar region of the cord (the pre-ganglionic fibers ending in the inferior mesenteric ganglia), the other, from the sacral portion of the cord through the nervi erigentes, the pre-ganglionic fibers of this set ending in small ganglia near the part innervated. The first set are for the most part motor, the latter inhibitory. Ordinarily the rectum is empty, and is only thrown into reflex peristalsis by the entrance of feces from above; **defecation** may be delayed by the contraction of the internal and external sphincters of the anus, the former consisting of involuntary, the latter of voluntary, muscle. The filling of the rectum gives rise to a desire to defecate, which may or may not be resisted; if the former, the contraction of the external sphincter is voluntarily strengthened; if the latter, the emptying of the rectum is assisted by a contraction of the abdominal muscles and inhibition of the external sphincter, the internal sphincter being at the same time reflexly inhibited. If by injury to the spinal cord voluntary nerve impulses are prevented from reaching the centers in the lumbar region, defecation becomes purely reflex, and may be carried on without the aid of the will. If the lumbar portion of the cord be destroyed, the reflex mechanism is put out of existence, and fecal incontinence results.

Vomiting is a reflex action which usually results from irritation of the gastric mucous membrane, and is preceded by a feeling of nausea. It may also be excited in a variety of other ways; for instance, mechanical irritation of the pharynx, intestinal obstruction, irritation of the uterus, as in pregnancy, and through the emotions. It is brought about mainly by strong contractions of the diaphragm and abdominal muscles, with simultaneous closure of the glottis. The stomach is thus compressed and its contents ejected through the esophagus, the cardiac sphincter being meantime relaxed. The walls of the stomach take some part in the expulsion of the food, but unassisted are ineffective. Vomiting is controlled by a center situated in the medulla.

QUESTIONS FOR CHAPTER IV.

What foods actually require digestion before they can be absorbed?

Does proteid undergo any preparation for absorption in the mouth?

If raw starch and saliva be mixed, will the digestion of the former be assisted by boiling the mixture?

If starch paste be acidified with HCl, the addition of what substance will enable saliva to digest the starch?

If starch and saliva be mixed, and a drop of the mixture be tested at intervals with iodin solution, why does the color reaction vary?

What step in digestion which is of more importance than the salivary digestion of starch is carried on in the mouth?

Why is it well to wash the teeth after each meal?

What secretion possesses the widest range of digestive power?

Can you readily arrange the digestive secretions in the order of their relative importance?

How is digestion affected by removal of the stomach?

In what respect is digestion most interfered with by removal of the pancreas?

Which of the following substances are of equal value as food, whether they be injected directly into the blood stream or introduced into the alimentary canal: dextrose, cane-sugar, soluble starch, lactose, egg-albumen, peptones, raw serum albumin, cooked serum albumin, levulose?

Supposing that pyloric and duodenal fistulæ have been established, so that there is no communication between the stomach and intestines, the animal may be fed through the mouth, or by introducing food and water directly into the duodenum. Which method of feeding will prove the more satisfactory?

What effect on digestion has the existence of a biliary fistula?

How does fat reach the blood stream?

How is digestion modified by the absence of hydrochloric acid from the gastric juice?

What constituents of food require no digestion?

What different factors play a part in determining the reaction of the intestinal contents?

If a small quantity of egg-albumen be absorbed from the intestines without having undergone digestion, how is it that it does not appear in the urine?

Under what circumstances does glycerin appear in the intestines?

How does dextrin differ from starch in its physical properties?

Where and how is bread and butter digested?

Why is it impossible to swallow six times in rapid succession without placing something in the mouth?

Have the emotions any influence over digestion? and is the effect of all emotions the same?

Why should the addition of horn shavings, which are indigestible, enable a rabbit to live on a milk diet?

How is it that proteid food does not result in peptone poisoning?

What becomes of the hemoglobin of the red cells which break down?

If soluble starch is absorbed from the intestine, why does it not appear in the blood?

What evidence of constipation may be shown by the urine?

What instances of synthesis in the body can you mention?

CHAPTER V.

METABOLISM AND NUTRITION.

THE food, after digestion and absorption, reaches the lymph-spaces of the gastric and intestinal mucous membranes. The proteids and carbohydrates pass, for the most part, from the lymph into the blood-capillaries, and are carried through the portal vessels to the liver; the fat, on the other hand, reaches the subclavian vein through the lymphatic vessels. During the absorption of fat, the lymph which passes through the lymphatic vessels of the mesentery, or lacteals, resembles milk in appearance, and is called chyle.

As we have seen, the carbohydrates reach the blood chiefly in the form of dextrose. If during absorption samples of blood be taken from the portal and hepatic veins and compared, it will be found that the hepatic blood contains the smaller percentage of sugar. Evidently, then, during absorption sugar disappears from the blood as it passes through the liver. If the liver of a well-fed animal be examined with the microscope, the liver-cells will be seen to contain an opalescent substance, which lies in that portion of the cell adjacent to the blood-capillary. On treatment with iodin, this substance gives a port-wine color reaction, resembling that given with iodin by erythrodextrin. It is a carbohydrate with the formula $(C_6H_{10}O_5)_n$, the molecule being smaller than that of starch; according to observations made on the freezing-point of its solutions, it may be represented as $(C_6H_{10}O_5)_{10}$. Like starch, glycogen is

nondialyzable; unlike starch, it is readily soluble. On starvation, glycogen rapidly disappears from the liver. If through the vessels of an excised, glycogen-free liver there be kept up an artificial flow of blood which contains dextrose, the percentage of sugar in the blood diminishes, and glycogen appears in the liver-cells. The conversion of sugar into glycogen is synthetic, and consists in the following reaction:

$$\underset{\text{Dextrose}}{10C_6H_{12}O_6} = \underset{\text{Glycogen}}{(C_6H_{10}O_5)_{10}} + 10H_2O;$$

that is, if we may take the above formula to represent glycogen. Not all the sugar which reaches the liver is converted into glycogen; a large proportion passes through the liver unchanged and is distributed, through the arteries, to the system in general. Sugar is rapidly taken up from the lymph by the muscles; a certain amount being converted by them into and stored as glycogen. Taken collectively, the muscles may contain as much glycogen as is found in the liver, but in muscle the percentage is smaller. Some of the sugar taken up by the muscles may perhaps at once, without undergoing previous elaboration, be utilized as a source of energy, being burnt up with the formation of carbon dioxid and water; it is probable, however, that an active muscle which uses an excess of sugar does not carry the oxidation of this excess beyond the formation of lactic acid, $C_3H_6O_3$, and that this lactic acid is completely oxidized elsewhere. Exercise reduces the amount of glycogen held in muscle, but that other substances may afford a supply of energy for muscular work is shown by the fact that a muscle may perform work after all its glycogen has disappeared. If a muscle is paralyzed by division of its nerve supply, an accumulation of glycogen goes on within it for several days. Other portions of

the sugar received by a muscle may, within it, be combined with some other substance,—for instance, proteid, —or it may be converted into and stored as fat. During starvation, when all the glycogen has disappeared from the liver and muscles, and when the body's store of fat has been used up, the blood still contains sugar which can only have originated from the proteids of the body, for sugar continues to be used by the tissues and yet does not disappear. Glycogen itself may be formed by the liver on a purely proteid diet, and this is not surprising, for proteids appear to contain a carbohydrate radicle in their constitution. It is probable that the liver having stored the carbohydrate excess which it receives during absorption, as glycogen, reconverts this store into sugar as it is needed by the rest of the body. That the liver can convert glycogen into sugar is certain, for it may be caused to do so by the stimulation of afferent nerves, and after death the change goes on rapidly. The postmortem change may be prevented by boiling the liver immediately after the death of an animal, possibly owing to the destruction of a ferment which may be contained within the cells and be answerable for the conversion. Again, by injuring the floor of the fourth ventricle, the liver may be caused to discharge its glycogen as sugar; whether the result is due to interference with the circulation of blood through the liver, or whether there exists in the bulb a definite center which regulates the metabolism of the liver-cells, is uncertain. In consequence of this change the blood will, for the time being, contain an excess of sugar, which the kidneys at once begin to excrete, giving rise to **Glycosuria.** This they do whenever sugar accumulates in the blood beyond the normal amount—0.1 to 0.2%. The appearance of sugar in the urine does not, therefore, indicate an abnormality of the kidneys, but merely that they

are discharging their normal function in removing from the blood an excess of sugar, for the occurrence of which they are not answerable. Sugar may accumulate in the blood from a variety of causes; the simplest cause is the taking of abundant carbohydrate food, but it is not easy in this way to produce glycosuria (sugar in the urine). **Disease of the pancreas** often, its removal always, causes glycosuria, but this has nothing to do with the digestive function of the pancreatic juice, nor, apparently, with those cells of the pancreas which produce this secretion. It seems probable that the groups of epithelioid cells which are known as Langerhans's bodies play an important part in regard to metabolism in general. Pancreatic diabetes continues in the absence of carbohydrate food, and even during starvation; the sugar in this latter case must originate from the break-down of proteids. Carbohydrate food increases pancreatic glycosuria. In the normal condition the pancreas evidently regulates the proteid and carbohydrate metabolism of other organs, but whether through the manufacture of some substance which is carried to them by the lymph and blood, or in some other way, is unknown. In the absence of this pancreatic influence, either more proteid than usual is converted into sugar or less sugar is used by the tissues; at the same time glycogen disappears from the liver. The liver can, however, if provided with levulose, convert this form of sugar into glycogen, and the levulose administered does not increase the glycosuria, but is utilized in the body.

Fat, after absorption, does not pass through the liver before entering the general circulation. There is no doubt that not all the fat of the food can, on reaching the cells of the body, be simply stored in the form in which it was taken, for the fat of different animals varies in composition. Human fat contains a larger

proportion of olein than does mutton or beef fat. If mutton or beef fat is to be stored, the excess of, for instance, stearin must be either split up and rearranged in the form of olein, or oxidized and excreted. Under certain conditions, however, some foreign fat may be stored in the adipose tissues of an animal, but this is unusual. Not all the fat stored in the body is derived from the fat of a food; a small proportion may be formed from sugar or glycogen, and probably more from proteid. It is the opinion of some investigators that almost all the fat of the food is oxidized by the cells as it reaches them, and that very little is stored as fat. Fat affords a large amount of energy to the system, which may be utilized in performing mechanical work, chemical work in the way of synthesis, and in maintaining the temperature of the body. The final products of its oxidation are carbon dioxid and water.

The waste products of **proteid metabolism** also include water and carbon dioxid, but there are formed, in addition, nitrogenous substances, the chief of which is **urea.** It is not to be supposed that the proteid metabolism which goes on within the cells, results in the direct decomposition of proteid into urea, carbon dioxid, and water, for in the muscles which contain the larger proportion of body proteids, and in which proteid metabolism goes on continually, little or no urea is to be found. That this absence of urea is not due to its rapid removal from the muscle by the lymph and blood has been proved by keeping up an artificial circulation through the vessels of a dog's hind limbs, the blood being oxygenated and passed through the vessels a number of times. Although the muscles retained their irritability, showing that they were uninjured, no urea accumulated either in the muscle or blood. Yet since proteid metabolism undoubtedly goes on in the muscles,

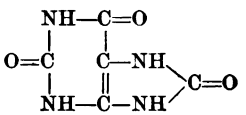
nitrogenous waste products of some kind must be formed there, and if not converted into urea in the muscles, they must undergo this change elsewhere in the body, for urea is the main nitrogenous waste product which is excreted. Most of the urea appears in the urine, but that it is not formed to any extent by the kidney has been proved by circulating oxygenated blood for several hours through the vessels of an extirpated kidney, at the end of which time almost no urea was found in the blood. Still more conclusive evidence that the kidney is not the organ chiefly concerned in the production of urea is furnished by the removal of the kidneys, after which operation urea accumulates in the blood. If blood be circulated through the limbs of a well-fed dog, and then through the liver of the same animal, these organs being isolated from the rest, urea appears in the blood. On its passage through the muscles of the limbs, the blood takes up some substance which, on subsequently passing through the liver, is converted into urea. That the **liver** is the organ in which most of the urea is normally produced may be shown by the removal of the liver, or by excluding it from the circulation. The urine of an animal whose blood is thus prevented from passing through the liver contains very little urea, showing that while urea may be formed in small quantities by other organs, it originates for the most part in the liver. In the absence of the liver, urea no longer forms the chief nitrogenous waste product; it is largely replaced by **ammonium salts.** This indicates that the liver may normally convert these ammonium salts into urea, and that it possesses this power, may be shown by circulating through the extirpated liver blood to which has been added the ammonium salt of carbonic acid, carbamic acid, or lactic acid; in either case the ammonium salt disappears and its place is taken by urea; for instance:

$$\underset{\text{Amm. Carbamate}}{NH_2.CO.ONH_4} = \underset{\text{Urea}}{(NH_2)_2CO} + H_2O.$$

Ammonium carbamate and ammonium lactate have been found in blood which is perfused through the isolated hind limbs of a dog; they also appear in the urine of an animal whose blood is prevented from passing througth the liver. Glycocol, the second of the series of amido-fatty acids of which carbamic or amido-formic acid is the first, may also be converted by the liver into urea. The amido-acids, such as leucin and tyrosin, formed in the intestinal digestion of proteids are after absorption carried to the liver and probably changed to urea; in diseases of the liver leucin and tyrosin may, in part, take the place of urea in the urine.

Another nitrogenous waste product found in muscle is **creatin**; this is probably excreted as urea, though if carried to the liver as creatin, it is converted into and excreted as creatinin. It is possible that creatin, before leaving the muscle, is changed to ammonium lactate, which on reaching the liver is, in turn, converted into urea. This creatin is the substance which gives to meat its flavor; it may be extracted by boiling, which, if prolonged, leaves the meat tasteless. Creatin is of little or no value as food, but renders the meat palatable and may act as a stimulant.

A nitrogenous waste product which is closely related to urea, and appears in the urine in small quantities, is **uric acid.** On examination of its formula, it will be seen to contain two urea groups united with a central chain of C.C.CO:



Through oxidation and hydrolysis, uric acid may be decomposed, with the formation of two molecules of urea and one of oxalic acid. If urea be administered to a bird, it is converted by the liver into uric acid; on the other hand, uric acid administered to a mammal is decomposed by the liver with the formation of urea. The amount of uric acid found in human urine is variable; there is usually one part of uric acid to about thirty-five parts of urea, but the ratio varies with the nature of the food. The amount of uric acid is increased by nucleoproteid food, though nuclein does not seem to be digested and absorbed to more than a small extent. It has been stated above that nuclein may be split up, with the formation of xanthin bases, which are closely related to uric acid. In leukemia, a pathologic condition in which the number of leukocytes in the blood is largely increased, the excretion of uric acid is also increased, perhaps owing to the break-down of leukocytes in unusual numbers, and the liberation of their nucleoproteid, which is then converted into uric acid. Not all the uric acid formed in the body may be expected to appear, as such, in the excretions, for much of it is probably converted into urea; the uric acid of the urine has perhaps reached the kidneys without passing through the liver.

Hippuric acid is a nitrogenous waste product which appears in human urine in small quantities only; it is more abundant in the urine of the herbivora, and, in the case of man, may be increased by eating vegetables, more especially fruits, which contain aromatic substances that are oxidized in the body, with the formation of benzoic acid. Hippuric acid appears in the urine, to a certain extent, even during starvation, and cannot therefore be entirely derived from food; aromatic compounds must originate in small quantities from the metabolism of proteids, and be converted into benzoic acid. The

benzoic acid, whether it be formed from food or from body proteids, is combined by the kidney with **glycocol** to form hippuric acid, and thus excreted.

It appears, then, that urea is not an immediate product of proteid metabolism, but that intermediate substances are formed, such as creatin, ammonium salts, possibly amido-acids, etc. It is certain that glycocol may be formed in the body, for the administration of benzoic acid results in the appearance of hippuric acid in the urine. As in the case of the nitrogenous, so in the case of the carbonaceous half of proteid, decomposition into the final waste products, carbon dioxid and water, is not immediate. Indeed, after a meal consisting of proteids, the excretion as urea of an amount of nitrogen corresponding to that administered is accomplished earlier than the excretion of the amount of carbon and hydrogen contained in the proteid. This indicates that the proteid is split into a nitrogenous and a nonnitrogenous part, the latter being perhaps transformed into glycogen, dextrose, or fat before it is utilized by the cells. It is known that these substances may be formed from proteid food, as has been stated above. It seems probable that fats and carbohydrates never form part of the bioplasm, but are held closely in contact with it within the cells, and utilized by it as a source of energy. Some of the proteid food is undoubtedly transformed into the living proteid of bioplasm, but it is unlikely that it all undergoes this process before being oxidized. In all likelihood, the fats, the carbohydrates, and most of the proteid, after entering the cell, suffer decomposition without ever becoming a part of bioplasm. Some of their decomposition products may subsequently undergo synthesis; for example, sugar may in this way be transformed into fat. The proteid of bioplasm, or, as it is called, tissue proteid, may be supposed to break down

but slowly; at the rate, it has been estimated, of about 1 % per diem.

By far the greater part of the proteid metabolism occurs in the muscles, and the most characteristic feature of muscle is its power of contraction, yet no relation exists between muscular activity and proteid metabolism. Muscular work is accomplished at the expense of the nonnitrogenous food-stuffs, namely, carbohydrates and fats; for the excretion of nitrogen is hardly affected by exercise, unless it be very violent, or unless there be a scarcity of fats and carbohydrates in the diet. On the other hand, muscular exercise is accompanied by a great increase in the excretion of carbon dioxid. Not all the energy liberated during contraction appears in the form of mechanical work; the larger portion is given off as heat. In the absence of a sufficient supply of nonproteid material, muscle is capable of utilizing proteid as a source of mechanical energy.

Internal Secretion.—Secretions are the products of glandular activity and are given off by a structure composed of one or more gland cells, epithelial in character, and are discharged upon a free epithelial surface, such as the skin or mucous membrane, or upon the closed endothelial surfaces of blood- and lymph-cavities, in the first instance the product being known as an external secretion, and in the second case as an internal secretion.

The internal secretions best understood are the secretions of the thyroid, adrenal, and pituitary glands, a secretion of the pancreas other than the pancreatic juice, and the secretion of the liver which modifies glycogen to the form of carbohydrate circulating in the blood. The testes and the ovaries are also supposed to give off internal secretions. We have seen that the pancreas exerts an important influence over the proteid

and carbohydrate metabolism of other organs, but this is not the only instance of the kind. The **thyroid body** is essential to the normal metabolism of the nervous system. If the thyroid be completely removed from a dog, the animal soon dies; but before death ensues there appear muscular tremors, spasms, and convulsions, which are of central origin, depending apparently upon abnormal metabolism in the cells of the spinal cord. Monkeys survive the operation longer; they also show muscular tremors, and myxedema may follow. **Myxedema** is a condition associated in man with atrophy of the thyroid; the symptoms are an overgrowth of the subcutaneous connective tissue, muscular weakness, sometimes spasms, and mental failure. The congenital form is known as cretinism, the child being idiotic and deformed. In man the removal of the thyroid is sometimes followed by myxedema, this variety being known as operative myxedema, or cachexia strumipriva. The symptoms may be relieved by injecting an extract made from the thyroid of some other animal into a vein or under the skin, or even by the administration of raw thyroid with the food. The normal thyroid evidently produces a substance, or substances, which enter the lymph and blood, are carried throughout the system, and take effect more especially on the central nervous system. In the absence of these substances, the metabolism of the nerve-cells becomes abnormal, but may be rectified by the administration of thyroid extract. The overgrowth of subcutaneous connective tissue is also due to abnormal metabolism. The thyroid produces an iodin compound, known as iodothyrin, or thyroiodin, which appears to be one of the substances answerable for thyroid influence, for this product is, on injection, effective in relieving the symptoms of myxedema. It is possible that this gland also possesses the power of neutralizing poisonous

products of normal metabolism. The irritability of the cardio-inhibitory and depressor nerves is reduced by the removal of the thyroid, and increased by the injection of iodothyrin, which tends also to lessen the irritability of the vasoconstrictors.

The removal of the **pituitary body** is, in dogs, followed by symptoms very similar to those seen on removal of the thyroid. In man, however, disease of the pituitary body is not accompanied by myxedema, but by an overgrowth of the bones of the face and limbs; a condition named acromegaly. Injection of extracts made from the posterior lobe into the vessels causes strengthening of the heart-beat and constriction of the arteries, apparently influencing directly the muscular coats of the vessels.

In dogs the removal of both **adrenal bodies**, or suprarenal capsules, is more quickly fatal than is the removal of either the thyroid or the pituitary body. The symptoms which precede death are extreme muscular weakness, weak heart-beat, and loss of vascular tone. In man a condition known as Addison's disease is associated with abnormality of the adrenals. The symptoms are similar to, but less acute than, those following the removal of the bodies; in addition, there occurs a peculiar bronzing of the skin, and sometimes of the mucous membranes. Dogs die too soon for this symptom to develop, but in rabbits, which survive the operation longer, pigmentation of the skin has occurred. Very marked effects are produced in normal animals by the intravascular injection of adrenal extracts. Muscular contraction is unusually prolonged, an effect resembling that of veratrin. The cardio-inhibitory center is strongly stimulated, the auricle ceases to contract, and the ventricle beats slowly; nevertheless the arterial blood pressure rises, owing to a direct stimulation of the

arterioles. This effect is transitory but energetic; if the vagi have been previously divided, the pressure rises to a great height. Extracts made from the cortical portion of the gland are inert; the active principle is to be obtained from the medullary portion only. A substance, **epinephrin,** which has been isolated from the extract, produces, on injection, the characteristic effects, and is evidently one of the active principles of the gland, though perhaps not the only one. We may conclude, then, that the adrenal body elaborates epinephrin, and perhaps other substances, which pass into the circulation and act on muscular tissue—skeletal, cardiac, and vascular—in such a manner that its tone is increased; in other words, they hasten muscular metabolism, perhaps more especially in regard to the oxidation of carbohydrates. In the absence of this influence the muscles lose their tone.

NUTRITION.

The body is constantly liberating energy supplied by the food, in which it has been stored by the plant; the ultimate source of this energy being the light and heat of the sun. The question to be discussed is, whether the different food-stuffs are of equal importance, and whether they are all necessary to the maintenance of life. It may be mentioned, in the first place, that digestion goes on more readily on a mixed diet. In all experiments on nutrition it is necessary to keep an exact account of the amount and quality of both the food and the excreta. In this connection it is usually sufficient, as far as the proteids are concerned, to estimate the amount of nitrogen excreted in the urine and feces. Proteids contain, by weight, from 15% to 17% nitrogen; consequently, the appearance of 1 gram of nitrogen in the excreta indicates the decomposition of about

6.25 grams of proteid. If the nitrogen excreted exactly equals the amount taken in the food, the animal is said to be in a condition of **nitrogenous equilibrium.** If the excreta contain less nitrogen than was taken in the food, nitrogen has been stored in the body; that is, proteid has been laid up. If more nitrogen appears in the excreta than was contained in the food, the excess must have been derived from the break-down of an unusual amount of body proteids. Even if nitrogenous equilibrium is maintained, the weight of the body may not remain constant, for **carbon equilibrium** does not always accompany an equilibrium in nitrogen. Carbon is contained in all classes of food-stuff, and while a condition of nitrogenous equilibrium exists, glycogen or fat may be stored up even on a purely proteid diet, leading to a deficit in the carbon excreted. On the other hand, fat or glycogen may be used up, and thus lead to the excretion of an excess of carbon, without interfering with the maintenance of nitrogenous equilibrium. It is therefore necessary, in making experiments on the relative value or the fate of the food-stuffs, to estimate not only the nitrogen, but also the carbon of the food and excreta.

During **starvation** metabolism does not cease, but goes on entirely at the expense of the carbohydrates, fats, and proteids of the body. After using up a certain proportion of this store, the animal dies; the period which lapses before death depending largely on the condition of the animal when starvation began. A lean animal will usually withstand the loss of about 0.4 of its body-weight; one that is fat may live until its weight has been reduced by 0.5; an adult human being may live for three weeks without food if supplied with water; children die in a few days, after losing about 0.25 of their weight. Fat disappears rapidly during

starvation; the proteids, as long as fat is being utilized, diminish very slowly. When most of the fat has been consumed the body falls back upon its store of proteids, and the excretion of urea is suddenly increased beyond that of the preceding period. While the fat lasts, the proteids are not used to any extent as a source of energy for the maintenance of temperature or for muscular work; but when the supply of fat has been exhausted, they must be so used; and even before this stage is reached, proteid must be decomposed in the formation of sugar, which never disappears from the blood. As starvation progresses metabolism diminishes, and the loss of weight grows less from day to day. The greatest loss in weight is sustained by the adipose tissue; then come the muscles; next the liver, spleen, etc., and, lastly, the heart and central nervous system, which suffer almost no loss, for they live at the expense of the other tissues. It might be supposed that a daily supply of proteid food, equal in quantity to the amount of tissue proteid which is broken down per diem during starvation, would suffice to keep an animal in a condition of nitrogenous equilibrium, but this is far from being the case. This depends upon the fact that proteid metabolism within the cells is stimulated by the reception of proteid food; the larger the quantity of proteid food which reaches the tissues, the more rapidly does proteid metabolism go on, and, as a result of this, the cells are capable of using practically all the proteid which is supplied to them. In one classic experiment a dog, during starvation, was found to consume his store of muscle at the rate of 165 grams per diem; at the same time he was burning up 95 grams of fat. When given 500 grams of lean meat, the nitrogen in his urine showed that 599 grams were decomposed; that is, that he had used up 99 grams of

muscle in addition to what he had received. At the same time 47 grams of fat were oxidized. In one day of starvation the animal had lost in weight 260 grams; the administration of 500 grams of meat only reduced this loss to 146 grams. On gradually increasing the amount of proteid food, from day to day, it was not until 1500 grams of meat were given that loss of weight was prevented; at this point nitrogenous equilibrium was established, and 4 grams of fat were stored up. Increasing the amount of proteid food still further did not lead to an appreciable storing up of proteid tissue; in fact, when 2500 grams were given, 2512 grams were decomposed, a loss of muscle to the extent of 12 grams. Fat was, however, stored up to the extent of 57 grams. Thus, if kept on a purely proteid diet an animal must, in order to maintain nitrogenous equilibrium, receive a certain amount of food; if more than this be given, it does not lead to the storing-up of the excess, for the cells become spendthrift and burn up all the proteid that they receive, in this way maintaining nitrogenous equilibrium at a higher level.

Proteid metabolism may, however, be reduced by a **mixed diet.** In the case of the animal which required 1500 grams of meat for the maintenance of nitrogenous equilibrium, an addition of 150 grams of fat to this amount of meat resulted in the building-up of tissue to the extent of 26 grams. Further than this, if 150 grams of the fat was given, the amount of proteid necessary was much less; under these circumstances the allowance of meat was reduced to 800 grams without the appearance of an excess of nitrogen in the urine. Therefore, a mixed diet is the more economic, for proteid is the most expensive of foods; it is better physiologically, for digestion is much less likely to become disordered. Carbohydrates are even more effective than

fats in the reduction of proteid metabolism; **gelatin** serves this purpose better than either. If, then, it is desired to reduce proteid metabolism as far as possible, in order that there may be a building-up of tissue proteid,—of muscle, for example,—it is best to give but a moderate amount of proteid, with a good proportion of one of the other foods, or, better still, a mixture of all the others. A mixture of the other foods, no matter how abundant the diet, will not, in the absence of proteid food, serve to maintain nitrogenous equilibrium; life will be prolonged, but death from proteid starvation is inevitable.

There is a difference of opinion as to the relative proportions in which the food-stuffs should be combined to form an ideal diet. The following is the diet recommended by Voit, and is intended for a man of 70 kilograms:

Proteid, 118 grams. Fat, 56 grams. Carbohydrates, 500 grams.

This diet is supposed to consist of both animal and vegetable food, and, consequently, cannot be expected to be absorbed *in toto*, for vegetable food is less readily digested than meat, owing chiefly to the cellulose covering.

In order to calculate the amount of **energy** supplied to the body by a given diet, we must know the combustion equivalent of each food-stuff; this is determined by burning the substance in question, and measuring the heat given off. In the case of fats and carbohydrates, the same amount of energy is liberated within the body as when the substance is burned outside the body, for the oxidation is in each case complete, the final products of combustion being carbon dioxid and water. Not all the energy contained in proteids is set free within the

body, for the end-products of proteid metabolism are, in the main, carbon dioxid, water, and, instead of nitrogen, urea, which is capable of undergoing oxidation and liberating energy. Besides urea, other oxidizable substances are formed in small quantities, and we must deduct the energy thus lost to the body from that introduced in proteid. The potential energy of a substance is expressed in calories. A **calorie** is the amount of heat required to raise the temperature of 1 gram of water by 1° C. The potential energy available to the body from 1 gram of proteid is 4100 calories; from 1 gram of fat 9300 calories; and from 1 gram of carbohydrate, 4100 calories. Adopting Voit's diet, as given above, the available energy will be:

Proteid, 118 grams × 4100 . . .	483,800
Fat, 56 grams × 9300	520,800
Carbohydrate, 500 grams × 4100 .	2,050,000
	3,054,600 calories.

This represents a diet suitable for a man doing ordinary work; increased labor entails the necessity of a larger food supply. As **muscular work** is performed almost entirely at the expense of the nonnitrogenous foods, it would seem rational to vary the diet by increasing the proportion of these when more work is to be done; experience has shown, however, that it is better to give more proteid also. The metabolism of the nonnitrogenous foods is also increased by exposure of the body to **cold**; that of proteids is not affected to an appreciable extent. The combustion equivalent of fat is higher than that of the other foods, and dwellers in cold climates are said to have a craving for fatty food, but there is no proof that fat is more readily used by the muscles in keeping up the temperature of the body.

Inorganic salts form as essential a part of the diet as

the foods which supply energy to the body. It has been shown that an animal fed on food from which the inorganic salts have been, as far as possible, removed dies sooner than similar animals which are starved. Inorganic salts are necessary for the neutralization of acids formed during metabolism; for instance, sulphuric acid, which originates from the oxidation of the sulphur contained in the proteid molecule. It is true that this may, to a certain extent, be neutralized by ammonia, also split off from proteid. This is by no means the only use of the inorganic salts, and, of course, neutral salts, such as sodium chlorid, are not used in this way. Amongst the uses of the inorganic salts in the body may be mentioned the following: they maintain the alkalinity of the blood and lymph, which is of the utmost importance, for an acid reaction rapidly destroys the irritability of bioplasm; they are of importance in regard to the osmotic pressure of the liquids and cells of the body; their presence is necessary to the solution of the globulins; from sodium chlorid is derived the chlorin for the formation of hydrochloric acid in the gastric glands; sodium chlorid, potassium salts, and soluble calcium salts are necessary to the activity of the heart; calcium salts are concerned in the clotting of blood, and so on. It would appear that the inorganic salts of the food must, to a certain extent, be in combination with organic substances, such as proteid; otherwise, they do not fulfill all that is required of them. A vegetable diet contains an excess of potassium salts, and seems to necessitate a supply of sodium chlorid, for the potassium salts react to some extent with the sodium chlorid of the blood, forming potassium chlorid and, for instance, sodium phosphate; this loss of sodium chlorid to the blood must be made good by its addition to the food. A supply of **calcium** for the building-up of

bone is needed especially by growing children, and this want is particularly well supplied by milk, which contains an abundance of calcium. **Iron** is another substance which is needed, chiefly in relation to the formation of hemoglobin; this is supplied in combination with nucleo-albumins in the food, but inorganic salts of iron may be absorbed. A diet consisting entirely of milk is unsuitable for any but infants, for it contains an insufficient quantity of iron. The infant contains within its tissues a store of iron which is slowly used up during the period of suckling; if confined to a milk diet beyond the usual time, it becomes anemic.

Water supplies no energy to the body, but is indispensable, for in its absence metabolism is impossible. It serves as a solvent for both food and excreta; in the removal of the latter, large quantities of water are eliminated, and must be replaced. The evaporation of sweat is a most important means of resisting the effect of a high temperature.

QUESTIONS FOR CHAPTER V.

During the absorption of carbohydrates, in which set of blood-vessels is the percentage of sugar the highest?

How may glycogen be most readily caused to disappear from the muscles?

Would you expect to cause glycosuria by puncturing the medulla of an animal which had for some time been fed on fat?

Is the appearance of sugar in the urine a necessarily serious symptom?

May it occur in health?

How is the percentage of sugar in the body increased after death?

How may we determine whether a certain substance is formed by a particular organ?

Compare the work done by the liver on a proteid diet with that done on a carbohydrate diet.

Under what circumstances would you expect an accumulation of urea in the blood?

Under what circumstances would you expect the urea of the urine to be replaced by ammonium salts?

Does sleep cause a variation in the rate of nitrogenous or non-nitrogenous metabolism?

Does all the urea which appears in the urine originate from the break-down of tissue proteids?

From what nitrogenous substances may urea be formed by the liver?

Can a molecule of urea be formed from one molecule of glycocol?

What are the waste products of muscular metabolism?

Which is the more nutritious, soup made by boiling meat or the insoluble residue?

Which is the more palatable? Why?

What changes occur in the composition of a calf's urine when it is weaned?

Is the formation of fat from sugar a synthetic or an analytic process?

Mention instances of synthesis and analysis which occur during metabolism.

What different factors prevent an accumulation of sugar in the blood?

What is meant by internal secretion?

Distinguish between internal and external secretion.

What is the physiologic treatment of myxedema?

Compare the effect of injecting epinephrin into the vessels of two animals, one of which is normal, the spinal cord of the other having been previously divided at the level of the seventh cervical nerves.

By what operative procedure may we insure the highest blood pressure on the injection of epinephrin?

Is the percentage of ammonia in the urine increased by the administration of ammonium carbonate?

How may it be increased?

How may muscular exercise be caused to increase the excretion of urea?

If an animal receives no nitrogenous food, does nitrogen disappear from the urine?

What organ receives, in proportion to its size, the smallest arterial blood supply?

Do all the end-products of hepatic metabolism enter the bile-ducts?

Do the amounts of urea and uric acid in the urine always vary together?

What is the surest means of increasing proteid metabolism?

If an animal be kept in a condition of nitrogenous equilibrium, does its weight necessarily remain constant?

Can an animal gain in weight when in a condition of carbon equilibrium?

Is it possible, by giving a large quantity of proteid food, to cause the appearance of proteid in the urine?

What is the final effect of an abundant diet containing an insufficient amount of proteid?

Supposing that an animal is receiving a daily allowance of 200 grams of proteid food, and that it excretes 30 grams of nitrogen, and 60 grams of carbon, what are we to conclude?

If an animal, on a diet of 200 grams of proteid, excretes 40 grams of nitrogen, and 120 grams of carbon, what are we to conclude?

Under what circumstances will moderate muscular exercise cause a deficit of nitrogen in the urine?

Why does the administration of a mineral acid reduce the proportion of nitrogen which is excreted in the form of urea?

Under these circumstances, how is this nitrogen excreted?

To what kind of diet is the addition of sodium chlorid of most importance?

During starvation the heart loses but little weight. Is the rate of cardiac metabolism slow as compared with that of skeletal muscle?

In choosing a diet for a child which is deprived of milk, to what inorganic constituent should special attention be paid?

What are the limitations to the use of milk as the sole article of diet?

CHAPTER VI.

EXCRETION.

THE waste products of metabolism,—carbon dioxid, water, urea, and other substances in smaller quantities, —the water and inorganic salts that are absorbed from the alimentary canal, and other material which, though absorbed, undergoes no chemical change in the body, are all excreted through various channels. **Carbon dioxid** is, in the main, excreted by the lungs, but is also eliminated, to a much less extent, in various secretions, such as the sweat, saliva, etc. Only a small proportion of the **water** which is excreted has originated in the course of metabolism; most of it represents that which was taken through the mouth. It is excreted by the glands of the alimentary canal; most of this, however, is reabsorbed. It is also excreted by the lacrimal glands, and, in much larger quantities, by the respiratory mucous membranes, sweat glands, and kidneys. **Urea** is found in traces in the saliva, bile, intestinal juice, and milk, but by far the majority is excreted in the urine.

The Urine.—The chief constituents of the urine are water, urea, uric acid, hippuric acid, xanthin bases, creatinin, conjugated sulphates, and inorganic salts. The origin of these substances has been already discussed. About 30 grams of urea is excreted per diem, the amount varying with proteid metabolism. The amount of uric acid is also variable, the average being about 0.8 gram;

it depends more upon the quality than the quantity of the food, and probably upon the extent of cell destruction; it is increased by exercise, and diminished by rest. Free uric acid is not found in fresh urine; it is excreted in the form of the more soluble urates; on standing, these may be converted into free acid, which is precipitated; this occurs most readily in acid urine, and is due to the reaction of the urates with the acid phosphates. The xanthin bases include xanthin, hypoxanthin, guanin, adenin, etc.; they are closely related to uric acid, which may be formed from them in the body. About 0.1 gram xanthin bases is excreted per diem. The creatinin of the urine is derived chiefly from the creatin of the food, and varies with the amount so taken, the average excretion being about 1 gram per diem. Hippuric acid occurs in the urine to the extent of about 0.7 gram per diem, and varies with the amount of vegetable food eaten. The conjugated sulphates have been mentioned in speaking of proteid putrefaction in the large intestine; conditions which favor the growth and activity of bacteria in the intestines increase the amount of these substances in the urine, while rendering the contents of the intestines antiseptic prevents their appearance. The urinary pigments are derived directly or indirectly from hemoglobin. Not the whole of the inorganic constituents of the urine are derived directly from the food; for instance, sulphuric acid and phosphoric acid are formed in the metabolism of proteids, the sulphates of the urine originating, for the most part, in this way, the phosphates to a less extent. Besides sulphates and phosphates, there are present carbonates and, in larger quantity, chlorids. Sodium, potassium, magnesium, and calcium are present; the relative quantity of each is indicated by the order in which they are mentioned; they are, of course, combined as salts.

The **acidity of the urine** is not due to the presence of free acid, but to the acid phosphates. Both acid and alkaline phosphates are present in the urine, the former predominating. The degree of acidity depends upon several factors; in the main, it represents the balance between the available bases taken in the food, and the acids produced in metabolism. The secretion of the acid gastric juice usually decreases the acidity of the urine secreted during gastric digestion, but this effect may be neutralized by the secretion of the alkaline saliva, bile and pancreatic juice. Vegetable food contains, in addition to alkalies, salts of organic acids, which, on oxidation, are converted into carbonates, and may be used in neutralizing the acids formed during metabolism; vegetable food, therefore, reduces the acidity of the urine; from animal food, on the other hand, the amount of acid formed exceeds the available bases, and the excess is neutralized by the conversion of alkaline into acid phosphates. The **specific gravity** varies from 1015 to 1025, and depends chiefly upon the amount of liquid absorbed by the alimentary canal, and the amount excreted through other channels. The amount of food consumed will, of course, influence the quantity of solids excreted. In making observations on the specific gravity of the urine, it is best to collect and mix the whole amount passed in twenty-four hours, beginning with an empty bladder. The **amount** varies from 1200 to 1700 c.c.

The secretion of urine depends chiefly upon the blood supply of the kidney. The kidney receives this supply, through the short renal artery, from the aorta; the pressure in the first set of capillaries—those forming the glomerulus—being, in consequence of this arrangement, high. The pressure in the capillaries of the kidney varies, of course, with the strength and rate of the heart-

beat; it also varies with the condition of the arterioles in other parts of the body, and, in addition, with the state of its own arterioles. The kidney will receive the most abundant supply of blood when the heart-beat is strong, the vessels of other parts constricted, and the local arterioles dilated. Under these circumstances the amount of urine secreted will be abundant. In cold weather the cutaneous vessels are constricted and more blood flows through the abdominal organs, including the kidney; in cold weather, therefore, more urine will be secreted than when it is warm, for in the latter condition the kidney receives less blood, the skin more, and the blood is concentrated by the free secretion of sweat. The kidney vessels are controlled by the central nervous system, through both **vasoconstrictor** and **vasodilator nerves** which leave the spinal cord in the lower thoracic nerves, enter the sympathetic, and pass through the splanchnic to the solar ganglia, where they probably end in contact with cells whose nonmedullated axons (post-ganglionic fibers) pass along the renal artery to the kidney. A division of these nerves results in a dilatation of the renal arterioles and an increased flow of urine; their stimulation ordinarily causes vasoconstriction and lessened secretion, but if stimulated with slowly repeated induction shocks, the action of the vasodilators is called into play. A division of the spinal cord in the upper thoracic region or division of both splanchnics leads to the dilatation of so many vessels that the general blood pressure is reduced to a point at which the dilatation of the kidney arterioles cannot result in an increased flow of blood through the kidney. The existence of a double set of capillaries in the kidney offers an unusually high resistance, and, to overcome this, a comparatively high blood pressure is necessary.

We do not know precisely **how the urine is secreted,** but the water and inorganic salts are probably filtered through the walls of the glomerular capillaries and epithelium of the capsule. The conditions are very favorable to **filtration,** for the blood pressure in the capillaries is high and that in the capsule must be low, as there is a free exit for the urine through the tubules. The filtration hypothesis has been disputed on the ground that ligation of the renal vein, while it must raise the intracapillary pressure and thus favor filtration, nevertheless puts a stop to the secretion of urine. This, however, may not be a valid objection, for the distention of the veins which results probably compresses the renal tubules, and, by preventing the exit of the urine, raises the pressure in the capsule toward that in the capillaries. The capsular epithelium may be supposed to act like a gelatin membrane, through which the water and salts of blood-serum may be filtered, leaving behind the proteids. In such a case the resistance to filtration does not consist only in that offered by the membrane to the passage of water and salts, for the proteids, owing to the osmotic pressure which they exert, tend to retain water and to prevent its escape from the serum. The **proteids** of plasma exert an **osmotic pressure** of from 25 to 30 mm. of mercury; this, then, must be added to the resistance which is offered by the membrane to filtration of water and salts. Thus, to cause filtration a somewhat greater force is needed, and it has been found that the secretion of urine ceases when the blood pressure falls below 40 mm. of mercury; it also ceases when the pressure in the capsule has been raised to within 40 or 50 mm. Hg of that in the capillaries.

The urine as it leaves the kidney is a very different liquid from any that could result from the mere filtration of blood plasma; if, then, filtration goes on into

the capsule, this filtrate must be greatly modified as it passes through the tubule toward the pelvis of the kidney. This undoubtedly takes place, for the more rapidly the urine passes through the tubules, the less it is modified, and the more it resembles the plasma in composition and reaction. When it traverses the tubules more slowly, time is given for its **concentration**, apparently by the absorption of water. If water is absorbed from the glomerular filtrate by the cells which line the tubule, they perform an immense quantity of work, for the osmotic pressure of the urine is much greater than that of the blood plasma. In one case the osmotic pressure of the urine of a cat which had been deprived of water was greater than that of its blood plasma by 498 meters of water; and the tubule cells, in transferring water from urine of this density to the blood plasma, must have exerted a tremendous force. The cells of which the **convoluted tubules** are formed are much more highly developed than those which line the capsule, and we may expect them to be more specialized in function. It seems probable that uric acid is excreted in this portion of the tubule; experiment has proved that such is the case in birds. With regard to the excretion of the more soluble urea, we have no knowledge as to whether it occurs in the capsule or tubules; we might expect that it would accompany the inorganic salts and water through the wall of the capsule. The urine as it leaves the capsule is alkaline in reaction, resembling the plasma in this respect; on its passage through the tubules it becomes acid, either through the addition of acid phosphates or the removal of alkalies.

Temporary ligation of the renal artery prevents the secretion of urine not only during the period of occlusion, but for some little time after the circulation is reestablished. Some take this as proof that filtration is

not answerable for the glomerular secretion. It is easy to see how this might incapacitate the tubule cells for the performance of work, but why it should put a stop to filtration is obscure; the glomerular epithelium is in some way rendered less permeable. That the epithelium of some part of the mechanism is injured, is evidenced by the appearance of albumin in the urine that is subsequently first secreted.

Diuretics are substances which increase the flow of urine; one class, known as saline diuretics, do this by bringing about hydremic plethora, and by causing a dilatation of the renal arterioles. Amongst the saline diuretics are sodium chlorid, urea, dextrose, sodium acetate, and many others. On injecting any of these into the blood, the first effect is a rise in the osmotic pressure of the plasma, the rise being proportionate to the resulting increase in molecular concentration. This increase of osmotic pressure causes the absorption of water from the lymph-spaces, and the blood will be diluted; we shall have a condition of **hydremic plethora.** The bulk of the blood being thus increased, the pressure within the vessels is raised, consequently the filtration of urine will be hastened. Even when the condition of plethora has disappeared diuresis may continue, for the renal arterioles remain dilated for some time. That the saline diuretics do not act through stimulation of the epithelium is proved by the fact that they produce no diuresis if, on their administration, an increased blood supply to the kidney is prevented. The dilatation of the renal arterioles is caused by a direct action of these diuretics either on the walls of the vessels or on the peripheral nervous mechanism. The existence of secretory nerve-fibers for the kidney has not been proved.

The urine is carried from the kidney to the bladder through the **ureter,** its passage being aided by rhythmic

contractions which sweep down the ureter every twenty seconds or so. These appear to be of muscular origin, since they may continue, after isolation, in the portions of the ureter which contain no nerve-cells. The ureter, on reaching the bladder, runs for a short distance obliquely through the bladder-wall; a valve is thus formed which prevents the backflow of urine from the bladder into the ureter, for a rise of pressure in the former will compress this portion of the latter.

Micturition.—When the bladder contains no urine, its muscular walls are in a state of slight tonic contraction; as urine enters, the muscles relax slightly, and, provided the urine is not introduced too rapidly, allow an accumulation of about 250 c.c.; when this point has been reached, rhythmic contractions appear and increase in force as distention goes on. The exit of the urine into the urethra is prevented by the elasticity of the neck of the bladder and of the surrounding parts, and, almost surely, by a reflex tonic contraction of the circular coat of muscle at this point. As the bladder fills a desire to urinate is felt. The emptying of the bladder may perhaps be instituted by a voluntary inhibition of the center which exerts a tonic control over the circular layer of muscle surrounding the neck of the bladder; at the same time, a voluntary contraction of the abdominal muscles raises the intravesical pressure, and assists in the expulsion of the urine. The chief factor in expelling the urine is, however, the **reflex contraction** of the muscular wall of the bladder itself. The exit of urine may be prevented or retarded by a voluntary contraction of the perineal muscles. After division of the spinal cord in the thoracic region, micturition may be carried on reflexly by centers situated in the lumbar cord. The **bladder is innervated** through two sets of nerves; one set, leaving the lumbar

region, enters the sympathetic, and, reaching the inferior mesenteric ganglia, is here connected with ganglion cells from which originate post-ganglionic fibers; these are distributed to the bladder through the hypogastric nerve and plexus. Stimulation of these nerves excites weak contractions of the bladder-wall, but sometimes the result is an inhibition of these muscles. The other set of fibers leaves the cord in the sacral nerves, and, without entering the sympathetic, reaches the hypogastric plexus through the nervi erigentes. These fibers end in small ganglia, situated in or near the bladder-wall, where they come into contact relations with the cells whose axons form the post-ganglionic link in this chain. These nerves, when stimulated, cause strong contractions of the bladder and expulsion of the urine. If the lumbar region of the spinal cord is destroyed, all nervous control over the bladder is lost, but, in the dog, the bladder empties itself at irregular intervals, a stimulus being afforded to the muscle by the stretching which results from distention; in man, the urine accumulates in the bladder to a certain extent, and, after this, as the urine enters from the ureters, the excess drains off through the urethra.

Secretion of Sweat.—The sweat is a watery fluid containing but a small percentage of solid matter. Sodium chlorid forms the chief solid constituent; there are also present other salts, fatty acids, and traces of urea. The sweat is ordinarily acid in reaction; but if abundant, is neutral or alkaline. In uremia the amount of urea is sometimes much increased. The amount of sweat secreted naturally varies considerably, being much greater in warm than in cold weather. Ordinarily, the sweat evaporates as fast as it reaches the surface; this is called invisible or insensible perspiration. The amount of insensible perspiration depends upon the

condition of the surrounding atmosphere; if the air be moist, less of the sweat will evaporate and the skin will be visibly damp; if the air be dry and warm, evaporation will go on more rapidly and the skin may appear dry, though the secretion may in reality be more abundant. When the skin is flushed, the secretion of sweat is usually, but not necessarily, increased. An abundant supply of blood to the sweat glands favors, but does not provoke, their activity, which is controlled by definite **secretory nerves.** These nerve-fibers leave the thoracic and upper lumbar regions of the spinal cord, and end in the ganglia of the lateral sympathetic chain; the post-ganglionic fibers, which arise from cells in these ganglia, pass through the gray rami to the various spinal nerve-trunks, and are distributed, through the cutaneous branches of these, to the sweat glands. The course is similar to that followed by the vasoconstrictors. The pre-ganglionic sweat nerves for the skin of the face and head end in the superior cervical sympathetic ganglion. It is not known whether there exists in the medulla a chief sweat center to which the spinal sweat centers are subordinate. As is well known, sweat may be secreted as a result of the emotions; in such cases the spinal centers are stimulated by involuntary nerve impulses descending from the brain; they cannot be voluntarily controlled. The secretion of sweat is ordinarily a **reflex** event arising from the stimulation of afferent cutaneous nerves, as by the application of heat. That it is not a result of the direct stimulation of the glands by heat is shown by the fact that exposure to heat, after the division of the nerves of a part, does not cause sweating of the paralyzed area. At the same time, the impossibility of provoking the secretion by increasing the blood supply is demonstrated, for, owing to the division of the vasoconstrictors,

the skin will be flushed, yet it will remain dry. On the other hand, stimulation of the peripheral end of the divided nerve, although it will bring about a paling of the skin, through the stimulation of the vasoconstrictors, will cause sweating of the part by exciting the sweat nerves. The result of stimulating the renal nerves has an entirely different effect on the secretion of urine.

The sweat centers may be directly stimulated by a rise in the temperature of the blood, or by venous blood. Atropin prevents the secretion of sweat by paralyzing the terminations of the secretory nerves; pilocarpin causes sweating by stimulating either the terminations of these nerves or the gland cells themselves; it possibly acts in both ways. Strychnin causes secretion by its action on the spinal cord; nicotin acts chiefly on the centers, but to a certain extent on the peripheral mechanism.

The **sebaceous glands** of the skin have not been shown to be controlled through the nerves. The sebum excreted by these glands consists of the debris which results from the degeneration of the epithelial cells of the glands themselves. It is an oily liquid made up of fats, fatty acids, cholesterin, proteid, salts, and water.

The ill effects of coating the skin with varnish are not due to interference with excretion through the cutaneous glands, but to the resulting dilatation of the cutaneous vessels and consequent loss of heat.

The Secretion of Milk.—Unlike the sebaceous and sweat glands, to which it is nearly related, the mammary gland is only occasionally active; in the male, with very infrequent exceptions, never. That the activity of this gland may, to a certain extent, be influenced by the nervous system is proved by the frequent instances of the cessation or modification of lac-

tation as a result of emotions or nervous disorder. There is, however, little or no experimental evidence from which we can gain an insight into the mechanism. Milk consists chiefly of water, holding in solution proteids, carbohydrates, and inorganic salts; and in suspension, globules of fat. The chief **proteid**, or nucleoalbumin, is caseinogen; in addition, there are smaller quantities of albumin and globulin. Lactose is the chief **carbohydrate**, and occurs in larger amount than the caseinogen. The **fat** consists of stearin, palmitin, olein, and smaller quantities of other fats. The inorganic constituents, with the exception of iron, closely correspond, in the proportion which they bear to one another, to those of the new-born animal.

The average proportions of the constituents of normal human milk and cows' milk are as follows:

	Human.	Cows'.
Fat	4. %	4. %
Sugar	7. %	4.5 %
Proteids	1.5%	3.5 %
Salts	0.2%	0.75%
Water	87.3%	87.25%

Before lactation begins the alveoli of the gland enlarge, the epithelium thickens, and the cells multiply. There appear within the cells, more particularly near their free border, granules and fat droplets which are extruded into the alveoli. At the beginning of lactation for a day or two the secretion varies from that which follows, in having numerous degenerated cells, a lower percentage of fat and sugar, and almost four times as much proteid. The effect of this early secretion, which is called **colostrum**, is to cause a free evacuation of the bowels of the nursing child. Colostrum is lacking in caseinogen, in spite of its high proteid percentage.

The normal physiological stimulus to the activity of

the gland cells is the emptying of the ducts, and although up to a certain point the secretion is continuous without external stimulus, when the alveoli and ducts are distended secretion is inhibited reflexly or directly by the high pressure in the ducts, to be resumed, and at a very rapid rate, when the child nurses. The activity of the gland varies with the physical stimulus of the sucking child. The amount varies under normal conditions from 10 to 16 ounces a day in the first week of lactation, to 30 to 40 ounces a day in the ninth month of lactation.

In an average nursing period of ten to twenty minutes, the amount obtained from a single breast varies from about one ounce in the first week to six ounces in the sixth week and later. Lactation usually ceases promptly when nursing is discontinued, but the application of pressure and cold, and the use of atropin and saline cathartics hasten the cessation of the glandular activity, and the process of involution in the gland.

The proteids of the diet if in excess increase the proteid caseinogen of the milk, also the fat and possibly the sugar. Lack of exercise will have the same effect as excessive proteid diet. The percentage of fats, carbohydrates, and proteids in the milk can be easily diminished by a free fluid diet.

QUESTIONS FOR CHAPTER VI.

What are the most prominent differences between the composition of the blood plasma and that of the urine?

What readily diffusible substance is found in the blood, but not in the urine?

What nondiffusible substance, when it is introduced into the blood, appears in the urine?

Carefully compare the effect of dividing the renal nerves, with that of stimulating them, (*a*) in regard to the renal blood supply, and (*b*) with respect to the secretion of urine?

Make a similar comparison of the effects of dividing and stimulating the sciatic nerve on the blood supply and activity of the sweat glands of the leg?

Compare the nature of the control exercised by the nervous system, on the one hand, over the secretion of urine, on the other, over the secretion of sweat?

Under what circumstances may the quantity of urine in health fall considerably below the average?

What effect have the seasons on the specific gravity of the urine?

How do you collect twenty-four hours' urine?

Why does the injection of a large quantity of normal saline solution into the vessels cause diuresis?

Supposing that the sodium chlorid of the plasma were incapable of passing from the glomerulus into the capsule, would the blood pressure required for the filtration of water be greater or less than the normal?

How do you account for the fact that the urine is, in respect to inorganic constituents, more concentrated than the plasma?

Would you expect the reaction of the urine to vary with its specific gravity? Why?

What effect has the administration of alkalies on the relations existing between different nitrogenous compounds of the urine?

What is the simplest method of producing diuresis?

Which of the normal constituents of the blood plasma, when present in excess, cause diuresis?

How would the secretion of urine be affected by increasing the percentage of proteids in the blood plasma?

How may the reaction of the urine be caused to resemble that of the blood?

How does starvation modify the urine of the herbivora?

What relation exists between the amount of blood supplied to the kidney and the reaction of the urine?

How may we determine whether a drug which exerts an influence over the secretion of sweat acts upon the sweat centers or on the peripheral mechanism?

How may we determine whether, on application of heat to the skin, the sweat glands are stimulated directly or reflexly?

What are the reasons for the intermittent function of the mammary glands?

Describe the normal course of lactation.

CHAPTER VII.

ANIMAL HEAT.

THE temperature of the body depends upon the liberation, in the form of heat, of the potential energy introduced in food. This is set free, not only from the food that has been absorbed and assimilated, but to a less extent from the food as it undergoes digestion in the alimentary canal. The larger proportion of heat is produced in the **muscles**, the process being under the control of the central nervous system. Next to the muscles in heat production come the glands, more especially the liver. In order that the temperature may remain constant, as it does within very narrow limits, exactly the same amount of heat must be liberated within the body as is given off from the surface and lost in the excreta. If the production of heat fails to keep pace with the loss, the temperature sinks; if the production of heat is more rapid than the loss, the temperature goes up. Both production and loss are very variable, but in the normal condition the one keeps pace with the other. In fever, if the temperature remains constant, the same is true; but in this case the adjustment fails during the rise of temperature.

If a cold-blooded, or poikilothermic, animal is exposed to cold, its temperature sinks to that of its surroundings; on exposure to heat its temperature rises. Warm-blooded, or homoiothermic, animals behave quite otherwise; for instance, a dog was placed in a chamber

the temperature of which was —91° C. (—130° F.); the first effect was a slight rise in the dog's temperature.

The metabolism of the muscles is governed by the central nervous system, and the cells of the nervous system are subjected to afferent impulses coming from the periphery; for instance, from the skin. If **cold** be applied to the skin, it stimulates certain afferent nerves, which in turn transmit impulses to the central nervous system, and cause the dispatch of efferent nerve impulses which hasten the chemical changes within the muscles; more material is oxidized within the muscle, and more **heat is produced.** If the cold be at all intense, the increased metabolism of the muscle will find visible expression in shivering, which consists of weak incoordinated contractions. The value of shivering is apparent. At the same time there occurs a **reflex constriction of the cutaneous arterioles,** brought about by the stimulation of the vasoconstrictor center through the afferent nerves of the skin. In consequence of this constriction, less blood will flow through the superficial vessels, and the **loss of heat** will be much less than it would be were more blood brought near the surface. The animal will feel cold, owing to the cooling of the surface and peripheral terminations of the sensory nerves, which carry impulses toward the brain, but its temperature may, in reality, be a little higher than usual. Amongst the afferent nerves of the skin are two sets of fibers whose peripheral terminations are so specialized that they are stimulated by slight changes of temperature. One set is stimulated by **cooling,** and transmits impulses which, on reaching the brain, give rise to a sensation of cold; they are unaffected by warmth. The other set is stimulated by a **rise of temperature,** the resulting sensation being one of heat. Whether the reflex

effects of changes of temperature are produced through these nerves is uncertain, but highly probable.

The metabolism of the muscles is controlled by nerve-cells situated in the spinal cord, and these have been called **thermogenic centers**; there is no reason to suppose that these cells are other than the ordinary motor nerve cells which govern the contraction of the muscles. They do not appear, in the absence of higher centers, to afford a mechanism which, on exposure to cold, suffices for the regulation of the temperature, through increased production of heat; for the animal whose spinal cord has been divided in the cervical region behaves as a cold-blooded animal; its metabolism is depressed by exposure to cold, increased by exposure to heat. The activity of the thermogenic centers of the cord appears to be regulated by centers situated in some higher portion of the central nervous system, these latter centers being influenced by the afferent impulses which are inaugurated by changes in the temperature of the surroundings.

A warm-blooded animal may be exposed to great heat and yet maintain a constant body-temperature. This is due, not so much to a lessened production of heat, as to an increased **loss of heat** from the surface. The application of warmth to the skin brings about a reflex dilatation of the cutaneous vessels; the skin flushes, more blood being brought near to the surface. If, however, the temperature of the surrounding atmosphere be much greater than that of the body, the effect of this event, taken by itself, would be a rise of body-temperature, for heat would be transmitted from the air to the blood. This, in the normal condition, does not happen, unless the heat be intense or the exposure be prolonged. We have already seen that the application of heat to the skin causes a reflex secretion of sweat; in the **evapo-**

ration of this sweat, a large quantity of heat is absorbed from the blood and carried off, as latent heat, in the resulting watery vapor. This is the most potent factor in preventing a rise of body-temperature on exposure to a warm atmosphere. It will be readily understood that the cooling of the skin in this way will be materially influenced by the state of the surrounding air. If the air be dry, evaporation will be favored; if moist, retarded. The effect of a hot bath is to raise the temperature of the body, for water is a much better conductor than air, and if warmer than the blood, will rapidly give up heat to the latter; at the same time, evaporation from the immersed skin will be prevented. A bath in water at 45° C. would soon prove fatal, while exposure to dry air at 125° C. might be borne with impunity for the same length of time. The first effect of a warm bath is a slight rise of body-temperature; after the bath is over there is a slight fall, but a return to normal soon follows. Although a cold bath abstracts much heat from the body, the metabolism is so stirred up that the first effect may be a slight rise of body-temperature; if the bath be prolonged, a slight fall may result, but on leaving the water the temperature rises a little above normal. An animal which possesses much subcutaneous fat is better protected from a loss of heat than one that is lean. The involuntary regulation of the body-temperature may be voluntarily assisted by the donning or doffing of clothing, and by taking or abstaining from exercise. The **average axillary temperature** is about 37.1°(98.8° F.). Small daily variations occur, the temperature being lowest between midnight and early morning, highest in the late afternoon; the effect of a meal is to slightly raise the temperature. If a warm-blooded animal is exposed to such intense cold that the heightened metabolism cannot keep pace with the great loss

from the surface, the temperature, after the preliminary rise, gradually sinks; unconsciousness supervenes, and is followed by death. The **hibernating** animals withstand the fall of body-temperature, which may go almost as far as 0° C., without ill effects. Metabolism proceeds at a minimal rate; the heart-beat is weak and infrequent; respiration is depressed and irregular, and the respiratory exchange almost ceases. The respiratory quotient sinks, for oxygen may be stored in the body; the animal may, in this way, gain slightly in weight. Cold-blooded animals may be frozen solid, and by gradual thawing be resuscitated; a snail has been reduced to a temperature of —120° C. without succumbing. In this case metabolism, of course, ceases; life becomes latent.

Changes of temperature affect proteid metabolism very little; the increased production of heat which ensues on exposure to cold is accomplished at the expense of the **nonnitrogenous foods.**

A warm-blooded animal poisoned with curari reacts to changes of temperature as though it were cold blooded. **Curari** paralyzes the terminations of the motor nerve-fibers, and thus deprives the central nervous system of its control over the chief thermogenic tissue of the body.

QUESTIONS FOR CHAPTER VII.

If heat is being continually produced within the body, why does not the temperature of the body continually rise?

What nervous centers are concerned in regulating the loss of heat?

Does the activity of these centers usually vary in the same direction?

In what respects is the regulation of body-temperature affected by a division of the afferent cutaneous nerves?

After this operation, will an animal better withstand exposure to heat or cold?

Compare the effect on the regulation of body-temperature which results from division of the ventral spinal nerve-roots with that which follows division of the sympathetic rami communicantes. In the former case, what reflex which normally follows exposure to cold will be prevented, while in the latter case it persists? What cold and heat reflexes will be rendered impossible in each case?

In very hot weather, will the administration of atropin tend to raise or lower the body-temperature?

Can we by means of the clinical thermometer determine the rate of heat production or heat loss?

Under what circumstances may the temperature of the body rise, while the production of heat remains constant?

Does a fall of body-temperature always depend on lessened heat production?

The sensation of warmth which on a cold day results from drinking alcohol is due to the warming of the skin by an increase in the cutaneous circulation, the activity of the constrictor center being depressed by the alcohol. What is the effect on the temperature of the body as a whole?

CHAPTER VIII.

MUSCLE AND NERVE.

THE physiology of muscle and nerve is best and most profitably studied in the laboratory; only a mere outline of the subject need be given here.

The general properties of skeletal, cardiac, and plain muscle are the same, but display minor differences. Skeletal muscles may be controlled by the will, but are also subject to reflex influences. The contraction of cardiac muscle is independent of, but regulated by, the nervous system. Plain muscle, with the exception of the ciliary muscle, is beyond the control of the will; its contraction is ordinarily reflex, but if it be deprived of nervous influence, it may develop an independent tone. The ease with which chemical changes may be set going within normal muscle renders it irritable; that is, it is capable of responding to a stimulus. Cardiac muscle is more irritable than plain muscle; plain muscle than skeletal. Muscle responds to mechanical, thermal, chemical, and electrical stimuli, and to the normal nerve impulse the nature of which has not been determined. In order that the application of a force may act as a stimulus it must be of sufficient intensity and duration, and must not be too gradual. On the application of a stimulus, a muscle shortens and thickens without changing its bulk; this is called contraction. That muscle is directly irritable may be shown by paralyzing the terminations of

its motor nerve with curari; in this condition it is still responsive to a stimulus.

Muscle is **extensible,** but does not stretch in proportion to the force applied; as the elongation is increased, the extensibility becomes less and less. On cessation of stretching, or other distortion, muscle, by virtue of its **elasticity,** resumes its normal shape.

When a muscle is stimulated it **contracts,** but there is a momentary delay in the appearance of the mechanical change; this is known as the latent period of muscle. When the stimulation is direct, the **latent period** amounts to about 0.004 second; if the muscle be indirectly stimulated, by applying the excitant to its nerve, the latent period is prolonged to about 0.007 second, the extra delay being due to the motor end-plate; in addition to this, the time which elapses between the stimulation of a nerve and the beginning of the mechanical response of the muscle will be influenced by the length of nerve over which the nerve impulse has to travel. The average **rate of transmission** of the nerve impulse is about 50 meters per second. The contraction produced by a single induction shock lasts about 0.1 second, but varies with the resistance offered and with the condition of the muscle. The contraction of plain muscle is very much more prolonged. The contraction of muscle may be divided into the period of shortening and the period of relaxation, the former being of somewhat less duration than the latter. The contraction of a muscle-fiber is not confined to the point stimulated, but sweeps over the whole fiber, as a wave, with a **velocity** of, in human muscle, about 10 meters per second.

The **extent of shortening** varies with the condition of the muscle, the strength of stimulus, the weight lifted,

the way in which the weight is applied, etc. Other conditions remaining the same, the degree of shortening is less in a fatigued than in a fresh muscle; the shortening occurs rather more slowly; the relaxation is very much prolonged. **Fatigue** depends on several factors; it is due in part to the consumption of the store of energy-containing material, in part to the accumulation of waste products. The motor nerve-ending is more sensitive to fatigue than the muscle itself. The cells of the central nervous system concerned in producing muscular contraction are also subject to fatigue. Contraction is much prolonged by veratrin and by adrenal extract. If, beginning with a current too weak to provoke contraction, successive single induction shocks of gradually increasing strength be passed through a muscle, a point will be reached where a just visible contraction results; this is known as a **minimal stimulus.** On further increasing the strength of stimulus, the extent of shortening will go on increasing up to a certain point, when the **maximal contraction** of which the muscle is capable will have been reached. Further increase of stimulus will not increase the extent of shortening. If, however, the muscle be stimulated at short intervals, with a stimulus that is just sufficient to cause a maximal contraction when the muscle is fresh, until it shows signs of fatigue, a further increase in the strength of the stimulus may now provoke a contraction equal to that of the fresh muscle.

Cardiac muscle responds to even a minimal stimulus with a maximal contraction.

If a muscle be caused to lift a **load,** any addition of weight will reduce the height to which the load is lifted, though it does not necessarily diminish the amount of work done. The **work** accomplished is the product of

the load by the height to which it is raised. If the muscle contracts without lifting a load, no external work is done; the energy resulting from the chemical change, upon which contraction depends, is all liberated as heat. If so great a resistance is opposed to the active muscle that it cannot shorten, no work is done, the energy set free all appearing in the form of **heat.** When the muscle is working to best advantage, not more than one-fourth of the energy set free is converted into work, and it is quite possible that even this one-fourth is first set free as heat which, by causing the anisotropic fibrillæ to absorb water, brings about their shortening.

The efficiency of all three kinds of muscle is greatest when they contract against a certain amount of resistance.

The term **isometric contraction** is applied to a muscle contraction made when the muscle is so fixed at both ends that it cannot shorten during contraction.

The term **isotonic contraction** is applied to a muscle contraction made under such conditions that the tension of the muscle remains constant throughout the contraction.

So far we have considered only the single contraction, or **twitch,** of muscle. In the body it is comparatively seldom that a muscle contracts for so short a period as 0.1 second; usually the contraction is more prolonged, and probably consists in the fusion of a number of single contractions, which are provoked by successive stimuli following each other so rapidly that time is not allowed for relaxation. If the **voluntary contraction** of muscle be graphically recorded, the tracing shows a slight rhythmic oscillation at the rate of about 10 to 12 per second, which appears to depend on the dispatch, by motor nerve-cells of the cord, of successive nerve impulses following each other at this rate. A similar form of contraction may be caused by artificial stimulation of muscle with rapidly repeated induction shocks.

When the stimuli are so rapidly repeated that a graphic record shows no undulations, the contraction is spoken of as complete **tetanus**; if time is allowed for a partial relaxation between contractions, it is an incomplete tetanus.

The breaking induction shock, when a submaximal stimulus is used, is more effective than the making shock; this depends on the induction apparatus. When the voltaic, constant, or battery current is used, closing the circuit (or making the current) is more effective than opening the circuit (or breaking the current). This depends upon changes in the irritability of the muscle, or nerve, as the case may be, produced by the passage of the current. The **irritability** of the muscle or nerve is raised at, and in the neighborhood of, the negative electrode, or **kathode**; it is lowered at the **anode** and in its neighborhood. It is supposed that a sudden rise of irritability serves as a stimulus. When the current is made, the irritability of the muscle is suddenly raised in the neighborhood of the kathode, the muscle is stimulated at this point, and a contraction instituted which travels along the muscle; the anodal end remains relaxed until this wave of contraction reaches it. The muscle as a whole then relaxes, though the kathodal end maintains a slight degree of shortening. This continues as long as the current flows evenly; when it is broken, the irritability of the anodal end, which had been depressed below the normal, suddenly rises to normal or a little above it, and, if the current be of sufficient intensity, a contraction will originate at this point. If the current be weak, no contraction will result, for the anodal stimulus is not so effective as the kathodal. The relative efficiency of kathodal and anodal stimuli may bear some relation to the fact that, in the case of the former, the rise of irritability is from normal upward, while, in that of the latter, it is a return to normal from a point below

it. If the current does not flow evenly, but rises or falls in intensity, there are corresponding changes of irritability in the muscle, and these may act as stimuli.

If a nerve which is connected with a muscle is stimulated by a constant current, the contraction of the muscle will depend upon the direction in which the current flows, and upon its intensity. What happens is shown in the following table, which illustrates the so-called **law of contraction.** If, when a current is passed through a nerve, the anode is nearest the muscle, it is called an ascending current; if the kathode is next the muscle, a descending current.

PFLÜGER'S LAW.

	ASCENDING		DESCENDING	
CURRENT:	make	break	make	break
Weak	C		C	
Medium	C	C	C	C
Strong		C	C	

The results of stimulation with weak and medium intensity of current may be understood from what has already been said, but, in the case of strong stimulation, further explanation is needed. The passage of a constant current not only modifies the irritability of a nerve, it also changes its **conductivity,** or power of transmitting the nerve impulse. With weak and medium currents, the change in conductivity is not sufficient to modify the result; but with strong currents, the effect is pronounced. While a strong current flows through the nerve, the conductivity is reduced, not only in the area between the electrodes, but for a short distance on either side of them, and just after the current ceases to flow the anodal end fails to transmit the im-

pulse. With a strong ascending or descending current the nerve is stimulated on making the current at the kathode; on breaking, at the anode. With an ascending current, however, while the impulse starting at the anode easily reaches the muscle, the impulse which results from making the current, and starts from the kathode, is by the lessened conductivity prevented from passing along the nerve, and no contraction ensues. On the other hand, with a descending current we get a making contraction, for the impulse starts from the kathode which is near the muscle, while the impulse provoked by the anodal stimulus fails to traverse the anodal area of depressed conductivity, and we get no breaking contraction. The condition induced in a nerve by the passage of a constant current is known as **electrotonus**; that at the anodal end, anelectrotonus; at the kathodal end, katelectrotonus. In order to stimulate a nerve in the intact body, one electrode is usually placed over the course of the nerve, the other on some indifferent part of the body, at, perhaps, some distance from the first. Under these circumstances, we cannot expect to obtain a demonstration of the law of contraction just described, for the current, instead of being confined to the nerve, will pass obliquely through it: if the anode be over the nerve, in a sheaf of diverging lines; if the kathode be over the nerve, in converging lines. In the former case the anelectrotonic area will be narrower than the katelectrotonic area; in the latter case the conditions will be reversed. Where the lines of force are the more concentrated, the current will be denser and its effects more pronounced. With a weak current, therefore, a contraction of the muscle (which is innervated by this nerve) will be most readily excited by the stronger of the two forms of stimulus, the making, when the area of katelectrotonus is concentrated by placing the kathode over the nerve. With an intensity

of current only just sufficient to give this result, no contraction can be obtained on breaking the current if the kathode is over the nerve; no contraction occurs at the make or break when the anode is over the nerve. If we now increase the strength of the current little by little, and use first one electrode and then the other with each rise in intensity, we shall reach a point at which, in addition to the result already obtained, we get making and breaking contractions when the anode is over the nerve. Of these, only the breaking contraction results from true anodal stimulation; the making contraction results from stimulation of the nerve in the katelectrotonic area. The katelectrotonic area is more diffuse than the anelectrotonic when the anode is over the nerve, but the greater efficiency of the kathodal stimulus equalizes the effects of the make and break. The strength of the current must be still further increased before we can obtain a breaking contraction with the kathode over the nerve, for with this arrangement the area of anelectrotonus is more diffuse. The results thus obtained will have appeared as follows:

LAW OF UNIPOLAR STIMULATION.

CURRENT.	ELECTRODE OVER NERVE.	CONTRACTION ON:	ABBREVIATION.
Minimal	kathode	closing circuit	KCC.
Medium	kathode	closing circuit	KCC.
	anode	closing circuit	ACC.
	anode	opening circuit	AOC.
Strong	kathode	closing circuit	KCC.
	anode	closing circuit	ACC.
	anode	opening circuit	AOC.
	kathode	opening circuit	KOC.

The formula for this normal sequence of reactions is

usually written thus, KCC, ACC, AOC, KOC, and indicates the order in which these events occur with increasing strength of current. KCC means kathodal closing contraction; AOC, anodal opening contraction, etc., closing the circuit being synonymous with making the current; opening the circuit, with breaking the current. When the nerves of a muscle are degenerating, the reaction, for some reason, varies from the normal, the anodal closing contraction being obtained with a weaker current than the kathodal closing contraction; this is known as the **reaction of degeneration,** and affords a means of diagnosis. Another important means of determining the condition of a muscle depends upon the fact that after the degeneration of its nerves, a muscle no longer responds to the **induced current,** while its irritability to the **constant current** rises above the normal. Its irritability should be compared with that of the corresponding muscle on the opposite side of the body. If the nerve fails to regenerate, the muscle, in time, undergoes complete atrophy.

When a muscle or nerve is **injured** at a certain point, the electric potential at this point is lowered; the injured portion becomes negative as compared with the uninjured portion. If the injured and uninjured parts be connected by means of a conductor,—a wire, for example,—a current will flow through the conductor from the uninjured, or positive, to the injured, or negative, pole of the muscle. This is called the current of rest, or **demarcation current.** When a nerve has been divided and is dropped back into the wound, the surrounding lymph may serve to connect the injured with the uninjured portion of the nerve, a current will be set up, and the nerve may be stimulated; this must be taken into account in experimenting upon divided nerves.

Not only is an injured part of nerve or muscle elec-

trically negative to uninjured parts, but **active** parts are negative as compared with resting parts; consequently when an uninjured portion of muscle or nerve becomes active, the difference of potential between this point and an injured point will be lessened, and, if the two points are connected by a conductor, the demarcation current will be, for the moment, weakened; this weakening of the demarcation current is called the **negative variation.**

Every nerve-fiber is an outgrowth from, or a process of, a nerve-cell. A nerve-cell usually has several processes; one, the axis-cylinder process, or **axon,** becomes a nerve-fiber; the others branch freely and are usually very much shorter than the axon; they are called **dendrites,** or protoplasmic processes. A nerve-cell with its processes constitutes a **neurone.** Each process is dependent for its existence upon connection with the parent nerve-cell; if a nerve-fiber be divided, the portion that is cut off from the cell invariably dies; regeneration can only occur through the growth of that portion of the axon which remains in connection with the nerve-cell. Division of the axon produces secondary effects on the cell itself; the cell-body shows signs of degeneration which, if regeneration of the axon does not occur, usually becomes complete. If conditions are favorable to regeneration and the axon grows out to, and makes physiologic connection with, the muscle, the cell recovers.

The nerve-cells of the posterior spinal root ganglia are originally bipolar; they give off but two processes. Later, these two processes unite for a short distance, rendering the cell-body unipolar. Each process becomes a medullated nerve-fiber; one, distributed to peripheral structures, functions as a dendrite; the other enters the spinal cord and is undoubtedly an axon. These cells suffer less from a division of their processes

than is the case with the cells of the spinal cord which give off efferent fibers.

Nerve-cells dispatch impulses through their axons; they are excited by stimulation of their dendrites. A nerve-fiber, if stimulated midway in its course, transmits impulses **in both directions,** but a visible result occurs at one end only. In the case of an efferent nerve-fiber,—a motor fiber, for example,—the only appreciable result is muscular contraction (except that, by means of a galvanometer, an action current may be shown to travel along the nerve in both directions); no change appears to be caused in the motor cell by the entrance of the impulse. In the case of an afferent nerve-fiber, stimulated midway between the periphery and the spinal cord, the visible result is brought about by the central discharge of the impulse in the spinal cord; no effect can be shown to occur at the periphery. When an impulse travels along a nerve-fiber, it spreads into any branches that are given off; the result of this is that if one branch of a motor nerve-fiber be stimulated near its muscular termination, the impulse which passes up the fiber toward the spinal cord will spread into any branch that happens to be given off at a higher level, and traveling down this, may cause the contraction of another muscle-fiber. This is called a **pseudo-reflex.** It is probable that a similar event may occur on the stimulation of the central termination of an afferent nerve-fiber within the spinal cord; the impulse passing back along the fiber may spread through a **collateral** branch which is given off from a point nearer to the parent cell, and stimulate other nerve-cells in the neighborhood of which this collateral ends. (See Fig. 7.)

Nerve-fibers do not seem to be susceptible of fatigue; they may be stimulated for many hours without loss of irritability or conductivity; their terminations, how-

ever, are readily fatigued. The conductivity of a nerve-fiber may be temporarily suppressed by freezing, or by pressure, or by exposure to ether vapor, etc.; also, as we have seen, by the passage of a constant current. If a nerve be crushed, its conductivity at this point is destroyed. If a nerve be divided and the two ends brought together, an impulse cannot be transmitted across the gap, continuity of the axis-cylinder being necessary to conduction.

The Chemical Composition of Muscle.—Muscle consists of the following constituents: water, 75%; proteids, including paramyosinogen, myosinogen, and albumin, 20%; fats, glycogen, phosphocarnic acid, and inorganic salts, in small quantities; and waste products of muscular metabolism, such as kreatin, xanthin bases, sarcolactic acid, etc.

Mammalian muscle, when its blood supply is shut off, very soon loses its irritability, and before long goes into **rigor mortis.** In this condition it is less elastic and less extensible, and, if no resistance be offered, it shortens; like that of contracting muscle, its reaction becomes slightly acid. The rigidity depends upon the precipitation or coagulation of paramyosinogen and myosinogen, these being converted into insoluble **myosin.** If perfectly fresh muscle be frozen, and subjected to pressure, there may be expressed from it a liquid of syrupy consistence called muscle plasma. If kept cold, the plasma remains liquid, but if warmed, it clots; from the clot separates a serum, of which the reaction is acid. The clot consists of myosin; the serum contains albumin. The proteids of muscle may be extracted by means of a 10% solution of ammonium chlorid, or a 5% solution of magnesium sulphate; on dilution, the extract clots, especially if it be kept warm. If before clotting occurs the extract be heated, the different proteids will be found to coagulate at different

temperatures. **Paramyosinogen,** a globulin, precipitates by heat at 47° C.; **myosinogen,** a proteid with many of the characters of a globulin, at 56° C.; **myoglobulin,** at 63° C.; **albumin,** similar to serum albumin, at about 73° C. The last two occur in quite small amounts. If a living muscle is heated gradually, its vitality is entirely lost, with its loss of irritability, when it has reached a temperature sufficient to coagulate the proteid of the lowest coagulation temperature; namely, the paramyosinogen at 47° C.

QUESTIONS FOR CHAPTER VIII.

Is the contraction of muscle dependent on katabolic or anabolic changes?

What is meant by the conductivity of muscle?

In order to produce complete tetanus, why is the frequency of stimulation that is required less in the case of a fatigued than in the case of a fresh muscle?

If an isolated muscle has been fatigued by continued stimulation, why does washing out its vessels with normal salt solution tend toward the recovery of its irritability?

Do the irritability and conductivity of a nerve-fiber always vary in the same direction?

What is the effect of treating a muscle with the extract made from a fatigued muscle?

If on passing a constant current through a muscle the intensity of the current be suddenly raised, at which electrode will contraction begin?

On stimulating a nerve-trunk in the intact body with the constant current, by the application of which electrode may we expect to succeed with the weakest current?

If in this respect the response is abnormal, what are we to conclude?

If a muscle fails to respond to the induced current, but is hyperirritable to the constant current, what must we conclude?

If a nerve has been divided, how can we determine when its regeneration is complete?

What causes an extremity to "go to sleep"?

CHAPTER IX.

THE NERVOUS SYSTEM.

The spinal cord, in the grouping of its nerve-cells and in its relation to the tissues of the different parts of the body, shows a segmental arrangement, though each segment is intimately connected with the rest of the central nervous system.

From each segment arises a pair of spinal nerves, through which relations with a particular segment of the body are established; there is, however, an overlapping of the innervation of a particular body segment, so that a given muscle receives nerve-fibers from two or three segments of the cord; this is especially the case with the muscles of the limbs. In consequence of this arrangement, a lesion which is strictly confined to one segment of the cord never deprives any one muscle of its nerve supply.

Each spinal nerve is connected with the cord by two roots, a ventral, or anterior, and a dorsal, or posterior, root, and each of these, where it joins the cord, is divided into several small rootlets, which are shown in figure 6. If the **anterior nerve-root** be divided, as at *a*, degeneration of the peripheral portion of the root occurs, and many nerve-fibers will be found to degenerate in the common nerve-trunk as far as its terminations in the muscles and sympathetic system. The fibers of the anterior root arise from cells which are situated in the gray matter of the cord, at the level of

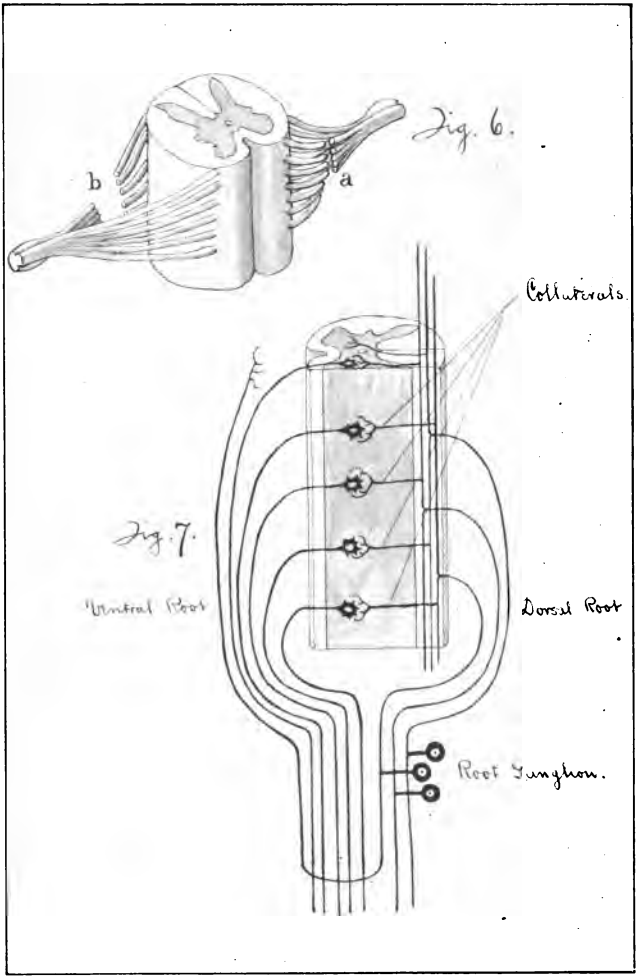


Fig. 6.
b
a
Collaterals
Fig. 7.
Ventral Root
Dorsal Root
Root Ganglion.

Figs. 6 and 7.

each fiber's exit. The portion of the anterior root which remains in continuity with the cord does not degenerate at once, for it has not been separated from its parent cell as is the case with the portion peripheral to the lesion.

Division of the **posterior spinal** nerve-root at a point between the root ganglion and the cord, as at *b*, figure 6, leads to degeneration of the rootlets which are left in connection with the cord, and degeneration of the posterior root-fibers may be traced within the cord, upward as far as the spinal bulb, downward for a short distance only. No degeneration occurs peripheral to the lesion, for the posterior root-fibers are the axons of posterior root-ganglion cells, and only that part of a fiber which is cut off from its parent ganglion cell is destroyed. If the **posterior root-ganglion** is removed or crushed, the resulting degeneration destroys not only the nerve-fibers which have grown from the ganglion into the spinal cord, but those also which are distributed to the periphery through the spinal nerve-trunk. Division of the **spinal nerve-trunk** at a point peripheral to the root-ganglion causes degeneration, peripheral to the lesion, of all its fibers; central to the lesion, of none.

Figure 7 shows the cell connection of the fibers of both roots. It will be noticed that the peripheral process of one posterior root-ganglion cell is represented as turning aside into the anterior nerve-root, instead of accompanying its fellows down the spinal nerve-trunk. The fibers which follow this course are distributed to the membranes of the cord, etc.

If the nerve-roots be divided as shown in figure 8, and the peripheral cut end of the **anterior root** be stimulated at *a*, there will result a contraction of the muscle *M*, to which some of the fibers of this nerve are

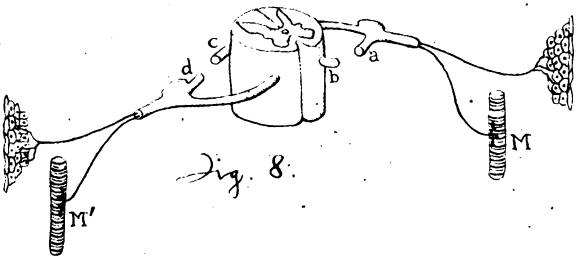


Fig. 8.

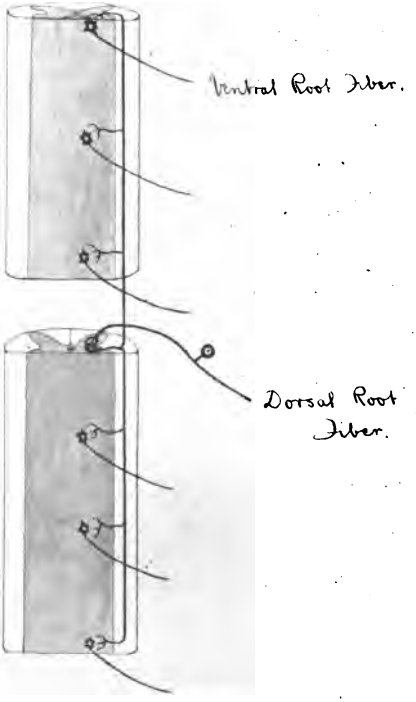


Fig. 9.

Figs. 8 and 9.

distributed. This result will not be prevented by previous destruction of the posterior root-ganglion, and degeneration of the posterior root-fibers. The anterior root contains motor nerve-fibers which are the axons of spinal cells. Stimulation of the central cut end of the anterior nerve-root, at *b*, produces no visible effect, for the resulting nerve impulses are evidently unable to spread to other neurones within the cord, though they probably reach the motor cells whose axons are stimulated.

On stimulation of the central cut end of the **posterior nerve-root,** at *c*, there may occur a reflex contraction of the muscle *M'*, and, if the spinal cord be intact and connected with the brain, sensation. The nerve impulses excited in the posterior root-fibers enter the cord and are transmitted by the ascending branches of these fibers toward the brain, and by their collateral branches (Fig. 7) to the motor cells of the gray matter. The motor cells are thus stimulated, and dispatch impulses through the anterior root to the muscles which they innervate. Stimulation of the peripheral cut end of the posterior root, at *d*, produces, as far as can be determined, no result. Impulses will reach the peripheral terminations of the posterior root-fibers in, for instance, the skin; but, even if the impulse actually reaches the structures in which the fiber ends, no effect seems to be produced.

The fibers of the anterior nerve-roots are **efferent**; they transmit impulses from the cord to the periphery. The fibers of the posterior nerve-roots are **afferent**; they transmit impulses from the periphery to the spinal cord. An afferent neurone and an efferent neurone together constitute the simplest form of **reflex arc.** A more elaborate form of reflex arc, including three neurones, is shown in figure 9. As will be seen, this

form allows a more widespread reflex, through the stimulation of a greater number of motor cells. The axons of the central, or mediate, cells do not leave the central nervous system, but ascend and descend the cord, thus bringing different levels into communication with one another. Some cross the median line and afford a basis for crossed reflexes; neurones of this class are called **commissural.**

The stimulation of the anterior root may give rise to sensation or to reflexes, for, as has been mentioned above, some of the posterior root-fibers bend back toward the cord through the anterior root (Fig. 7); this is called **recurrent sensibility.**

In some of the lower animals, for instance, the fish, reflexes may be carried on by one segment of the cord after it has been isolated from the rest. As a general rule, the reflex irritability of the spinal cord is increased by excluding the impulses which normally descend from the brain. In the **spinal animal**—that is, one whose cord, or the greater portion of it, has been separated from the brain—it is easier to predict the kind of reflex that will be evoked by a given stimulus. If a spinal dog be held in the vertical position, the stretching of the skin of the pendent legs will give rise to a reflex raising of these. A minimal stimulus applied to the skin will provoke reflex contraction of muscles on the same side of the body; if the intensity of the stimulus be raised, the reflex may spread to the opposite side also. Reflexes spread tailward more readily than headward; it is more difficult to cause reflex movement of the foreleg by stimulation of the skin of the hinder part of the body than to cause movements of the hind limb by stimulating anteriorly. It is impossible to cause reflex simultaneous contraction of antagonistic muscles; if the flexors of a limb con-

tract, the extensors relax, and vice versa. The relaxation is due to an inhibition of the motor cells which control the antagonistic muscles. The skeletal muscles possess a **tone** which is of reflex origin; they are kept in a state of slight tonic contraction by weak motor impulses which continually reach them from the spinal centers, the activity of these centers resulting from the constant arrival of afferent nerve impulses from the periphery. If the motor cells be inhibited by impulses coming to them from the brain, or from a contracting antagonistic muscle through afferent nerves, their activity is lessened and the muscle which they govern is allowed to relax; its tone disappears. The division of its nerve supply puts an end to the tone of a muscle, as may be readily understood. During sleep muscular tone disappears. When a muscle loses its tone, it also loses what is known as **myotatic irritability,** which consists in the power of a muscle, when stretched, to respond to a mechanical stimulus. The **knee-jerk** which is evoked by tapping the patellar tendon when the extensor muscles are put on the stretch depends on myotatic irritability; it is not a true reflex, but is a response to the direct mechanical stimulation of the extensors, by the sudden extra tension resulting from the tap on the tendon. Although it is not a reflex contraction, it is, nevertheless, dependent on the existence of reflex muscular tone; an injury to the reflex arc, upon the integrity of which muscular tone depends, abolishes the knee-jerk; this is the case in tabes dorsalis, in which the posterior nerve-roots are affected. The knee-jerk also disappears when injury is done to the lumbar region of the cord, wherein lie the motor cells concerned. On the other hand, a lesion situated above this region may, by preventing cerebral inhibition from reaching these cells, render them more irri-

table than in the normal condition, and result in exaggeration of the knee-jerk. The extent or absence of myotatic irritability is, consequently, a symptom of diagnostic import. The **condition of the reflexes** innervated by different portions of the spinal cord is of great assistance in determining the position of a lesion; as instances, the following may be mentioned: the scapular reflex, controlled by the fifth cervical to the first thoracic segments; palmar reflex, seventh cervical to first thoracic; epigastric reflex, fourth to seventh thoracic; abdominal reflex, seventh to eleventh thoracic; cremasteric reflex, first to third lumbar; knee-jerk, second to fourth lumbar; gluteal reflex, fourth and fifth lumbar; plantar reflex, first and second sacral; Achilles tendon reflex, third to fifth sacral. These centers become hyperirritable when, by injury to the pyramidal tracts, the control exercised by the brain is eliminated, though, in man, complete division of the cord is followed by depression of the centers situated below the lesion. The reflexes are abolished by degeneration of the spinal centers which control them; the muscles concerned show the reaction of degeneration, are hyperirritable to the constant current, lose their irritability to the induced current, and finally atrophy.

The Sympathetic System.—In the thoracic and upper lumbar regions many of the nerve-fibers of the anterior and posterior spinal nerve-roots do not pass out to the periphery through the corresponding nerve-trunk, but enter the sympathetic system through the **white rami communicantes.** The efferent fibers which follow this course probably originate from a group of small nerve-cells which in these regions of the cord are situated in the dorsolateral portion of the anterior horn, the group being known as the intermedio-lateral. These efferent fibers are medullated, like the other fibers of

the anterior root, but are smaller than the rest. They all end in one or other of the sympathetic ganglia, and are called **pre-ganglionic sympathetic fibers.** The sympathetic system includes two chains of lateral, or vertebral, ganglia ; and collateral, or prevertebral, ganglia which are found in the solar plexus, mesenteric plexus, and, smaller ones, in close proximity to the viscera.

The pre-ganglionic sympathetic fibers which are concerned in the innervation of the vessels, glands, or musculature of the abdominal and thoracic viscera, pass through the lateral sympathetic chain, to end in one of the prevertebral ganglia. Here they make physiologic connection with sympathetic nerve-cells, the relation being one of contact. From the ganglion cells are given off the **post-ganglionic fibers,** usually nonmedullated, which reach the tissue concerned (Fig. 5).

The pre-ganglionic sympathetic fibers which are concerned in the innervation of the vessels of the skeletal muscles or in the innervation of the vessels, plain muscle, and glands of the skin, end in one or other of the ganglia of the lateral chain. The corresponding post-ganglionic fibers, which originate here, pass, by way of the **gray rami communicantes,** into the spinal nerves and thus reach the periphery (Fig. 4).

The posterior root-fibers which enter the sympathetic system are distributed to the viscera (Fig. 10), and form one of the channels through which afferent impulses pass from the viscera to the central nervous system. Afferent impulses are also carried from the heart, lungs, liver, stomach, etc., by the pneumogastric nerve to the medulla, and from the pelvic viscera by the second, third, and fourth sacral nerves to the spinal cord. The **pain** resulting from disease of the viscera is often **referred** by the patient to a definite area of the

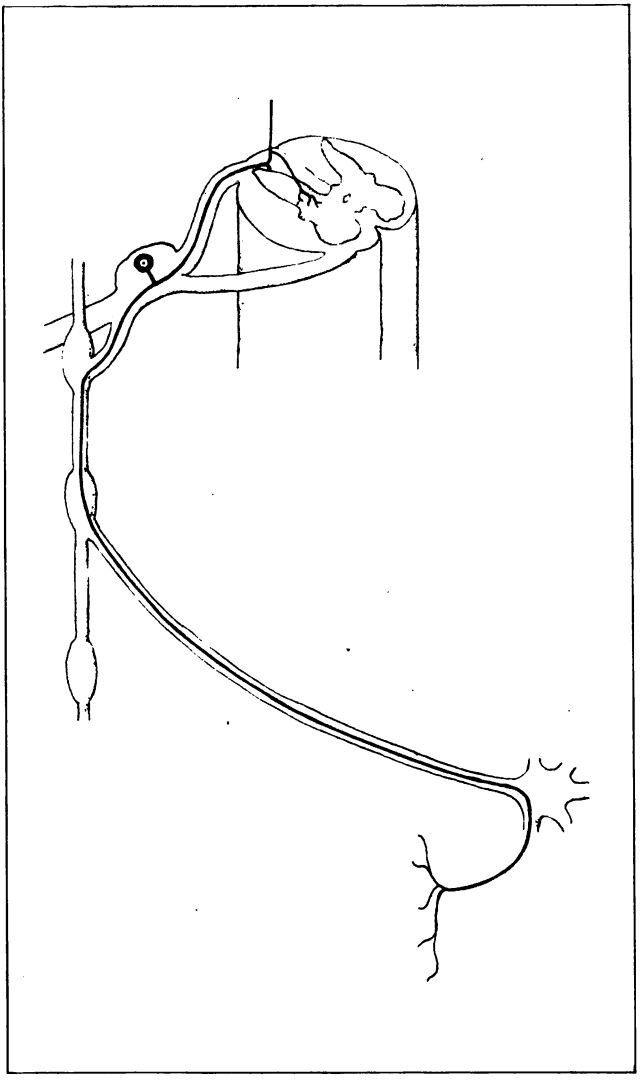


Fig. 10.—The course of an afferent sympathetic fiber.

skin; this area being that which is supplied with afferent fibers by the same dorsal spinal nerve-root which transmits afferent impulses from the viscus in question. Even in the case of the skin, with which we are so familiar, it is only through past experience that we are able to localize the point of origin of a given cutaneous sensation. It would seem that the afferent nerve-fibers which enter the cord through a given nerve-root, whether they be cutaneous or visceral, make very similar connections within the central nervous system. Thus we are very apt to be misled into confusing the sensation resulting from an unusual visceral irritation with those which arise from stimulation of an area whose afferent fibers may discharge their impulses at much the same point within the cord, and do so more frequently. Not only does this confusion of sensations exist; even the reflexes which may be excited by stimulation of a given cutaneous area are intensified by irritation of the viscus whose afferent fibers enter through the same nerve-root.

Whatever the destination of an efferent pre-ganglionic sympathetic nerve-fiber, it leaves the spinal cord in the thoracic or upper lumbar region, and originates from a cell situated in the cord at the level where it emerges. These pre-ganglionic fibers all end in sympathetic ganglia, and the post-ganglionic fibers, which originate from the ganglion cells, are all distributed to cells (plain muscle, of the vessels, viscera, and skin, cardiac muscle, and gland cells) the activity of which is involuntary. The sympathetic system supplies nerve-fibers of various function; as, vasoconstrictors and vasodilators, of wide distribution; viscero-motor fibers, for the spleen, uterus and Fallopian tubes, intestines, etc.; cardio-augmentors; viscero-inhibitory fibers, such as those supplied to the stomach and intestines;

pupillo-dilators; secretory fibers for the salivary, lacrimal, and sweat glands, and for the small glands of the oral, nasal, and pharyngeal mucous membranes; pilomotors, which control the plain muscle of the skin and bring about the erection of the hair and the condition known as goose-skin.

The arrangement of **two other sets** of peripheral nerve-fibers, one set emerging from the central nervous system in certain cranial nerves, the other, in the (second) third (and fourth) sacral nerves, resembles that of the sympathetic nerve-fibers. These fibers, also, are distributed to gland cells, cardiac and plain muscle-fibers. Each set consists of pre-ganglionic and post-ganglionic fibers. The fibers included in the **cranial set** vary in function. They are: pupillo-constrictors and fibers of visual accommodation, in the third cranial nerve; in the seventh and ninth cranial nerves, secretory fibers for the salivary glands, and glands of the lips and cheek, and vasodilators for the salivary glands, tongue, soft palate, and floor of the mouth; in the tenth and eleventh cranial nerves, viscero-motors for the esophagus, stomach, small intestines, ascending and horizontal colon; broncho-constrictors; cardio-inhibitory fibers; and secretory fibers for the gastric glands and pancreas. The fibers of this class which leave the cord in the **sacral nerves** all pass through the nervus erigens; they are viscero-motors for the bladder, descending colon, and rectum; vasodilators for the mucous membrane of the rectum and external genitalia, and inhibitory fibers for the plain muscle of the latter.

After division of the extrinsic nerves of the intestines, **peristalsis** may be even more vigorous than usual, and is probably controlled by a local nervous mechanism which acts reflexly. Stimulation of the mucous membrane still causes the characteristic contraction above,

and inhibition below, the point stimulated. Between the muscular coats of the alimentary canal, extending from the lower part of the esophagus to the anus, is the ganglionated plexus of Auerbach, and in the submucosa is Meissner's plexus; these appear to act as the local reflex mechanism for the peristalsis of the intestines. Normally an influence over peristalsis is exerted through the motor fibers of the pneumogastric and inhibitory fibers of the sympathetic nerves.

Returning to the **afferent nerve-fibers,** which enter the cord through the posterior nerve-roots, we have to consider the channels through which various sensations and reflexes are provoked. These fibers are distributed to the skin, muscles, tendons, viscera, and, in fact, to all parts of the body, save those which receive similar fibers through the cranial nerves. The skin is supplied with fibers whose peripheral terminations have been specialized in such a way that they are irritable to a particular form of stimulus. One set is stimulated by the application of **heat,** another by **cold,** and a third by **pressure.** In addition, there are fibers of wider cutaneous distribution, the endings of which are less specialized for response to given forms of stimulus; the sensation resulting from stimulation of these depends on the intensity of the stimulus; weak stimulation gives rise to an indefinite sensation known as **common sensibility;** if the stimulus be strong, no matter whether it consist in the application of pressure, heat, cold, chemical irritants, or electric stimulation, the resulting sensation is one of **pain.** However, in order to induce pain the intensity of the stimulus must be greater than is required to cause a sensation of, for instance, pressure, when it is applied to a specific nerve-ending. The degree of temperature to which the ending of a cold-nerve responds depends upon the temperature of the

skin at the time of application, and upon the rapidity with which the lowering of the temperature is brought about. The endings of cold-nerves may also be stimulated by the application of heat, but the resulting sensation is one of cold. The endings of cold-nerves are more numerous than those of heat-nerves; the endings of pain-nerves, more numerous than those of either of the other varieties.

Many of the afferent nerve-fibers which are distributed to the skeletal muscles end in muscle spindles, which consist of several muscle-fibers inclosed in a connective-tissue covering, within which the nerve-fibers ramify upon the muscle. When a muscle contracts or is stretched, these nerve-endings are stimulated, impulses are transmitted to the central nervous system and give rise to sensations which are described as **muscle sense.** By means of these impressions, we form an idea of the force and extent of the contraction of our muscles, and of the resistance opposed to their contraction; the pressure nerves of the skin are also important in this respect.

The afferent nerves of the **viscera** are concerned, for the most part, in reflexes of which we are unconscious; it is seldom that we experience visceral sensations; operations upon the normal abdominal viscera are painless; yet under certain circumstances these nerves may transmit impulses which excite intense pain.

As was stated above, the **central axons** of the posterior spinal root-ganglion cells, on entering the cord, divide into ascending and descending branches. The former are the longer, but vary in length. Both branches finally end in the gray matter, some ascending as far as the medulla; both give off **collaterals** (Fig. 7), which also end in the gray matter. The course of these fibers is in the posterior, or dorsal, columns of white matter,

each of which is subdivided into a **dorsomedian** and a **dorsolateral tract** (Figs. 11, 12). The fibers ascend at first in the dorsolateral tract, but, in the case of those of the lumbar nerves which reach the medulla, they later pass over into the dorsomedian tract, and thus reach the dorsomedian nucleus, or **nucleus gracilis** of the medulla, where they end. The dorsolateral tract, when it reaches the medulla, consists chiefly of fibers which carry impulses from the upper extremities; these fibers end in the dorsolateral nucleus, or **nucleus cuneatus.** These two nuclei serve as cell stations for the forwarding of impulses to the cerebellum and to the cerebrum, in response to impulses received from the periphery. They contain nerve-cells whose axons follow several different paths; some, the internal arcuate fibers, curve ventralward, cross the median line, and ascend in the fillet, or lemniscus, on the opposite side, toward the cerebrum (Fig. 11). Probably, only the minority of these reach the cortex; many of them end at lower levels in, for instance, the optic thalamus and corpora quadrigemina. The optic thalamus seems to afford another cell station on the way to the cerebral cortex. In the internal capsule the ascending fibers are found in the posterior portion of the dorsal limb.

The dorsal nuclei are connected with the cerebellum, through the restiform body, by two sets of fibers; one set, arising from the cells of these nuclei, passes directly into the restiform body on the same side; another set, the external arcuate fibers, follows the same course as the internal arcuates until, the median line having been crossed, they reach the surface, and, passing in front of the pyramid, enter the restiform body, and so, the cerebellum. The fibers which thus reach the cerebellum carry impulses to the roof nuclei and cortex of the inferior vermis. It is highly probable that impulses

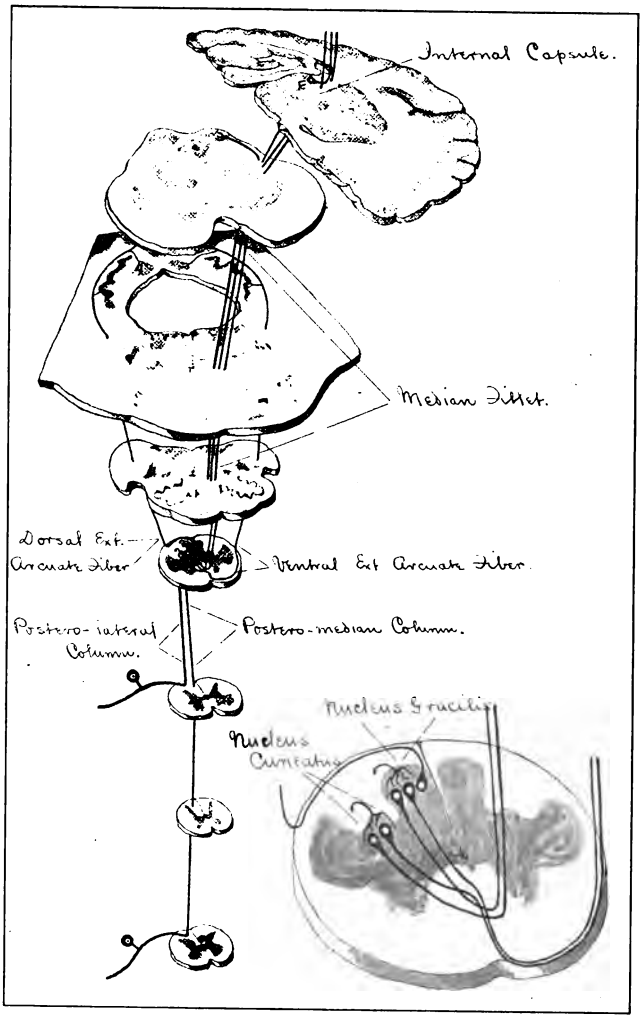

Internal Capsule.
Median Fillet.
Dorsal Ext. Arcuate Fiber
Ventral Ext Arcuate Fiber
Postero-lateral Column.
Postero-median Column.
Nucleus Gracilis
Nucleus Cuneatus

Fig. 11.

which are concerned in **muscle-sense** ascend the cord and reach the cerebellum and cerebrum over the paths just described; there is some evidence that the impulses concerned in tactile sensibility, pressure sense, also follow this course.

If the posterior nerve-roots be divided, the degeneration of fibers within the cord is confined to those in the dorsal columns. Division of the cord itself is followed by the degeneration of not only the dorsal column

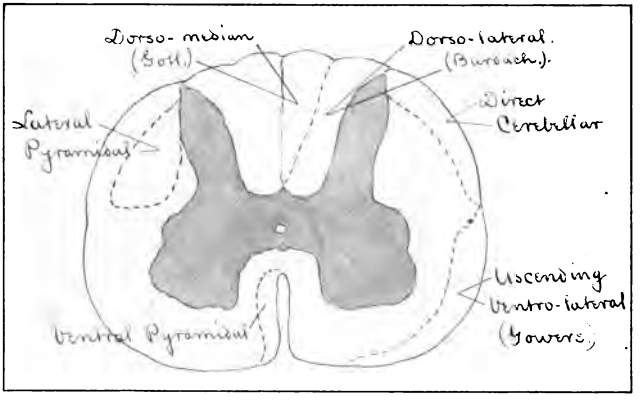


Fig. 12.—The ascending and descending tracts of the spinal cord, in cross-section.

fibers which have entered below the point of lesion, but of fibers situated in other tracts. Figure 9 shows central cells whose axons ascend and descend the cord for short distances, in that part of the white matter which is adjacent to the gray. Many of these will be divided in making a transverse section of the cord, and degeneration will occur in that portion of the fiber which is separated from its parent cell; in those which have grown from below upward, and are divided, de-

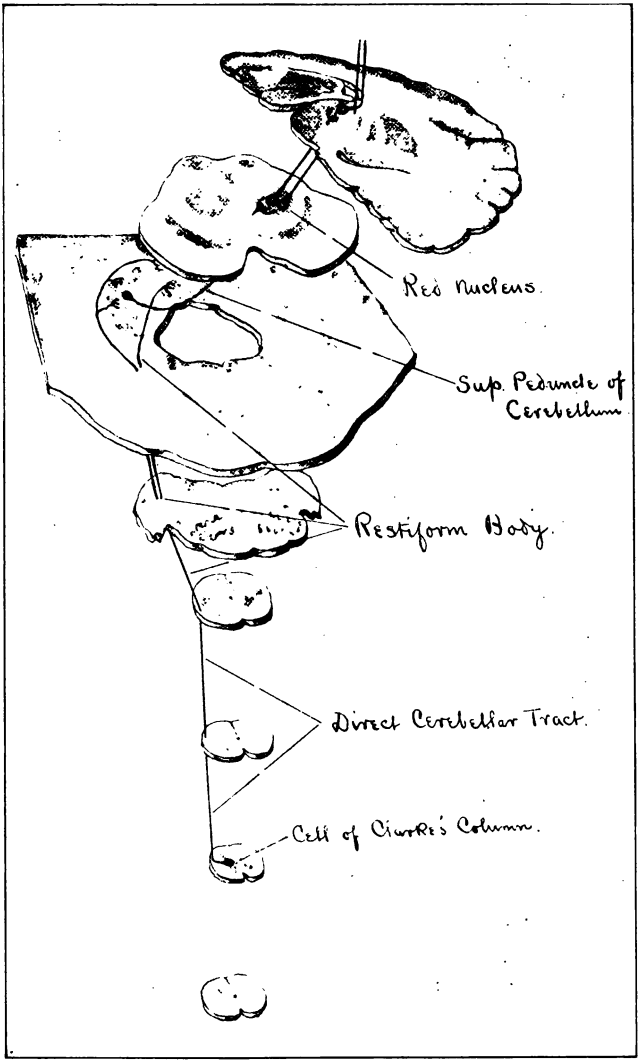


Fig. 13.—Serial sections showing the course and connections of the direct cerebellar tract. (The upper section is disproportionately reduced.)

generation will occur above the lesion; those which have grown downward, and are divided, will degenerate below the lesion. In addition to these, fibers of much greater length will be found to degenerate both above and below the point of section.

One distinctly marked ascending tract, or tract of fibers which degenerate above the point of section, is the **direct cerebellar tract** (Figs. 12 and 13). The fibers which constitute this tract originate from a group of cells which persists throughout the thoracic cord, and is known as the column of Clarke, or the vesicular cylinder. The group lies at the base of the posterior horn of gray matter, and toward its median border. In the neighborhood of these cells many of the dorsal column collaterals end, and thus bring the group under the influence of the afferent impulses which enter through the posterior roots. The direct cerebellar tract ascends the cord without undergoing decussation and enters the cerebellum through the restiform body, its fibers ending chiefly in the cortex of the vermis, partly on the same, partly on the opposite side. What afferent impulses are carried by this tract is uncertain. It must be remembered that impulses which reach the cerebellum may cause the dispatch of cerebellar impulses to the cerebrum, for the two are intimately connected through the superior cerebellar peduncle, or brachium conjunctivum (Fig. 13).

Another ascending tract is that of Gowers, or the **anterolateral ascending tract** (Figs. 12, 14). Its fibers originate from cells situated in the gray matter, on the same and on the opposite side of the cord; they pass for the most part into the cerebellum, some ascending as far as the level of the inferior corpus quadrigeminum, and then curving downward into the vermis; others entering the cerebellum through the restiform body.

Fig. 14.—Serial sections showing the course and connections of the anterolateral ascending tract. (Upper section disproportionately reduced.)

Mixed with these fibers are some which do not enter the cerebellum, but end in the corpora quadrigemina and optic thalamus. This tract appears to convey impulses concerned in **temperature sensations** and **pain.** Destruction of the ventrolateral portion of the spinal cord on one side leads to loss of the perception of painful stimuli, of heat and cold, when these are applied to the skin on the opposite side of the body below the lesion.

Of the **cranial nerves,** the first, second, fifth, both divisions of the eighth, the ninth, and tenth contain afferent nerve-fibers. In the case of the fifth, eighth, ninth, and tenth, these afferent fibers behave much as do the afferent fibers which enter the cord; on entering the medulla they divide into ascending and descending branches, the latter being, however, the longer; from these, collateral branches are given off.

The afferent fibers of the **tenth cranial nerve,** vagus or pneumogastric, have a wide distribution and carry impulses from the heart, lungs, pharynx, larynx, trachea, esophagus, stomach, intestines, liver, pancreas, and spleen. These fibers, on entering the medulla, divide into short ascending branches which end in the **nucleus alæ cinereæ,** and long descending branches which form the **tractus solitarius,** or solitary bundle. These give off many collaterals which end amongst cells, that are scattered along this tract and form the nucleus of the solitary bundle. The axons of the cells of these two nuclei follow a course similar to that of the internal arcuate fibers which originate from the cells of the gracile and cuneate nuclei. They curve through the reticular formation to the median line, cross it, and ascend in the opposite fillet; some fibers, however, enter the posterior longitudinal bundle, and ascend in this toward the brain (Fig. 15). The further course of the fibers which

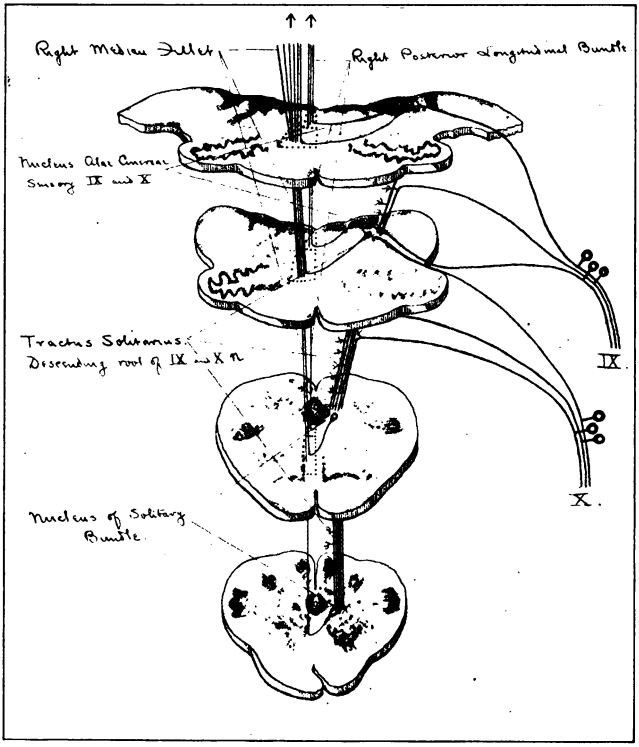


Fig. 15.—The afferent fibers of the ninth and tenth cranial nerves.

enter the fillet is the same as that already described (Fig. 11). These fibers, before they decussate, give off collaterals which end in the reticular formation, and may be supposed to influence the cells of the cardio-inhibitory, respiratory, and vasoconstrictor centers which are situated in this neighborhood.

The **ninth cranial nerve,** or glossopharyngeal, contains afferent fibers which carry impulses from the tongue, pharynx, Eustachian tube, etc. Its central connections are much the same as those of the pneumogastric (Fig. 15).

The cochlear, or **auditory division of the eighth cranial nerve,** consists of afferent fibers which are distributed to the cochlea, and carry auditory impulses. These fibers are the axons of the bipolar cells of the **spiral ganglion;** in the medulla they end in two nuclei, the **ventral** and **dorsal cochlear nuclei.** The axons from the cells which form these nuclei pass through the trapezium and striæ acusticæ, as shown in figure 16, to the superior olive on the opposite side; some, however, end in the superior olive on the same side. Many of the fibers end in the olive; others pass through it and ascend, with the axons of olivary cells, in the lateral fillet. The fibers of the lateral fillet end on the same side in the inferior corpus quadrigeminum, in the medial geniculate body, and a few in the superior corpus quadrigeminum; and on the opposite side, in the inferior corpus quadrigeminum. From the geniculate body impulses are forwarded to the cerebrum; the corpora quadrigemina probably act as centers through which sounds may bring about reflex movements of the head and eyes. The auditory impulses pass chiefly to the opposite side of the brain, but it will be seen from the diagram (Fig. 16) that there are several means of communication with the same side of the brain.

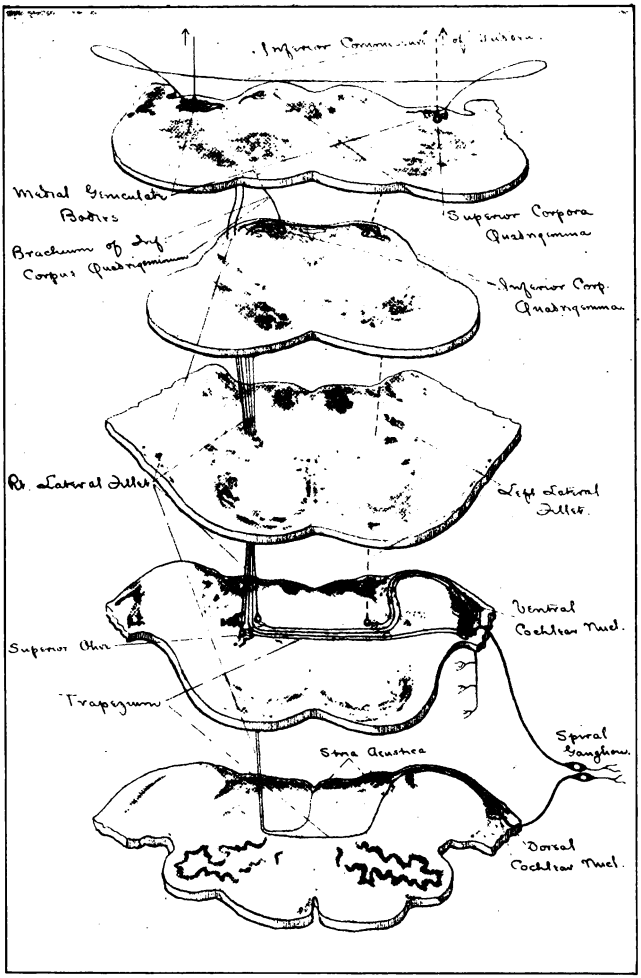


Fig. 16.—The cochlear nerve.

The **vestibular division of the eighth cranial nerve** consists of afferent fibers which arise from the vestibular ganglion cells. The peripheral processes of these bipolar cells end in the vestibule and semicircular canals. This nerve carries afferent impulses, by means of which we are informed of movements of the head or of the body as a whole, and which assist in the reflex and voluntary maintenance of **equilibrium.** On entering the medulla at the lower border of the pons, they end, for the most part, in four nuclei—namely, the **superior, lateral,** and **medial vestibular nuclei,** and the **nucleus of the descending, or spinal, vestibular root.** Some fibers pass directly into the cerebellum. The axons of the vestibular nuclear cells follow several different routes; axons from each nucleus enter, and ascend in the median fillet and posterior longitudinal bundle, mainly on the opposite side; from the lateral and superior nuclei fibers also pass into the cerebellum, while others descend the cord; both these sets probably play a part in reflex equilibration (Fig. 17).

The **fifth cranial nerve,** trigeminus or trifacial, contains afferent fibers which carry impulses from the skin of the face, from the conjunctiva, and from the mucous membranes of the nose and mouth. Some of the fibers distributed to the tongue may carry impulses which result in sensations of taste. The afferent fibers of the trigeminus originate from cells situated in the **Gasserian** ganglion. On entering the pons they divide into very short ascending branches which end in the **chief trigeminal nucleus,** and very long descending branches, the spinal root, whose collaterals end amongst the cells of the **substantia gelatinosa** which forms the nucleus of the spinal root. The axons which arise in these nuclei give off collaterals in the reticular formation, and probably

ascend in the median fillet on the opposite side of the median line (Fig. 18).

The **second cranial**, or optic, nerve differs entirely in its method of development from the other afferent nerves that we have considered; it may, however, be described with them. It consists chiefly of afferent fibers which are the axons of **retinal ganglion cells.** Light which falls upon the retina does not stimulate these cells directly, but takes effect upon the rods and cones of the outer layer. Between the rod and cone cells and the ganglion cells, mediate the bipolar neurones of the retina. The axons of the retinal ganglion cells enter the optic nerve, and pass along it to the optic chiasma; here the fibers from the nasal half of the retina, and some of those which originate from the cells in the macula lutea, decussate, and enter the opposite optic tract; the fibers from the temporal half of the retina do not cross, but proceed through the optic tract on the same side toward the brain. The optic tract, then, contains fibers from the temporal half of the homonymous retina, fibers from the maculæ luteæ of both eyes, and fibers from the nasal half of the contralateral retina. These fibers reach and end in the **external geniculate body**, the pulvinar, and the anterior corpus quadrigeminum. Axons originating from the cells of these bodies transmit impulses through the optic radiation to the occipital cortex, which constitutes the **visual area** of the brain. The anterior corpus quadrigeminum forms a center through which **visual reflexes** are probably inaugurated; fibers originate here which decussate and descend through the posterior longitudinal bundle into the spinal cord, giving off, on their way, collaterals which terminate in the motor nuclei of the nerves which innervate the muscles of the eye. They very probably

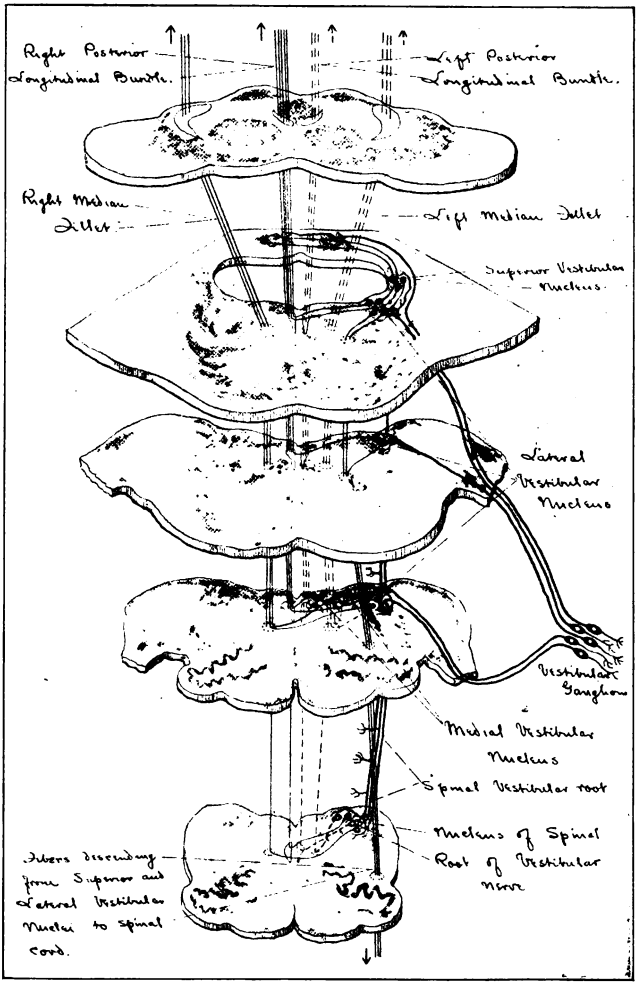


Fig. 17.—The vestibular nerve.

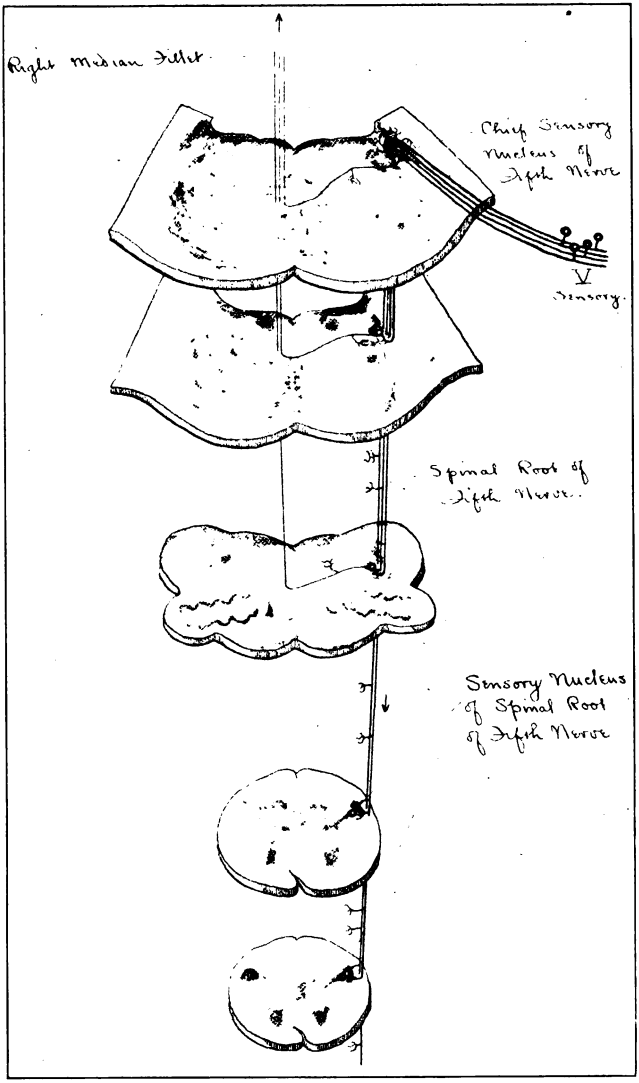


Fig. 18.—The afferent fibers of the fifth cranial nerve.

also bring about reflex turning of the head in response to visual stimuli (Fig. 19).

The **first cranial**, or olfactory, nerve consists of the axons of cells situated in the olfactory mucous membrane of the nose; the dendrites of these cells reach the surface; their axons pass through the cribriform plate of the ethmoid bone, and enter the olfactory bulb. The axons end here, in the olfactory glomeruli, in contact with the dendrites of the mitral cells, whose axons form the second link in the chain which transmits olfactory impulses toward the brain. The mitral cell axons run in two directions; one set enters the anterior commissure, and, passing through it, reaches, on the one hand, the opposite olfactory bulb, on the other, the opposite hippocampus. Of the other set, the majority of fibers pass through the lateral olfactory gyrus to the uncus, where they end. The fibers of the medial root end in the trigonum, where they make cell connections which bring them into communication with other parts of the olfactory area. From the cells of the uncus, in contact with which the fibers of the lateral root end, axons pass to the hippocampus. The hippocampal neurones, in turn, make, through the fornix, manifold connections, some of which are shown in figure 20. Some of the fibers end in the nucleus habenulæ, whence neurones descend through Meynert's retroflexed bundle; others end in the corpus mammillare, and make connections with neurones whose axons divide into two branches, one ascending to the anterior nucleus of the optic thalamus, the other descending.

Sensory Cortical Areas.—Certain areas of the cortex cerebri are closely associated with sensation, and it is to these areas that impulses provocative of sensation are carried. Destruction of the left occipital lobe leads to blindness of the left half of each retina; destruction of

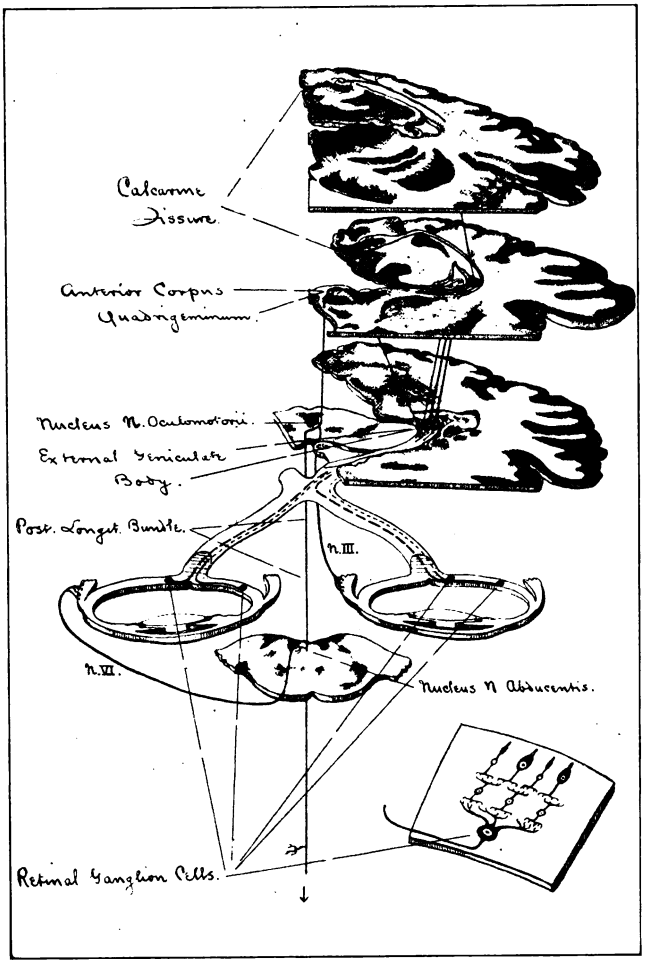


Fig. 19.—The optic nerve.

the right occipital lobe causes blindness of the right half of each retina. The cortical area lying on either side of the calcarine fissure is probably concerned in reception of impulses from the macula lutea, or area of most distinct vision, of each eye. Figure 21 shows the visual and other sensory areas of the cortex, those for cutaneous sensibility being, however, of doubtful location.

Descending Tracts of the Spinal Cord.—Having considered the channels through which afferent nerve impulses are carried from the periphery to the brain, there remain for description the connections between higher centers and the peripheral efferent neurones. After transverse sections of the spinal cord, degeneration of certain nerve-fibers occurs below the lesion; these degenerated fibers are, of course, the processes of cells which are situated at various levels above the lesion. There are many cells in the gray matter of the cord whose axons enter the white columns, and ascend or descend, for comparatively short distances, to end in the gray matter at different levels; on their way through the white matter they give off collaterals which also enter and end in the gray matter (Fig. 9). In addition to these, there are fibers which descend into the cord from higher levels. Two such tracts have already been mentioned—namely, the fibers which descend from the **vestibular nuclei** (Fig. 17), and those which descend in the posterior longitudinal bundle from the superior **corpus quadrigeminum** (Fig. 19). Both these sets of fibers descend through the ventrolateral columns of the cord, and give off collaterals to the gray matter. Fibers also descend, in all probability, from the **cerebellum**, though these may be interrupted by cell stations in the inferior olives, or in the pons. There is no doubt that the cerebellum,

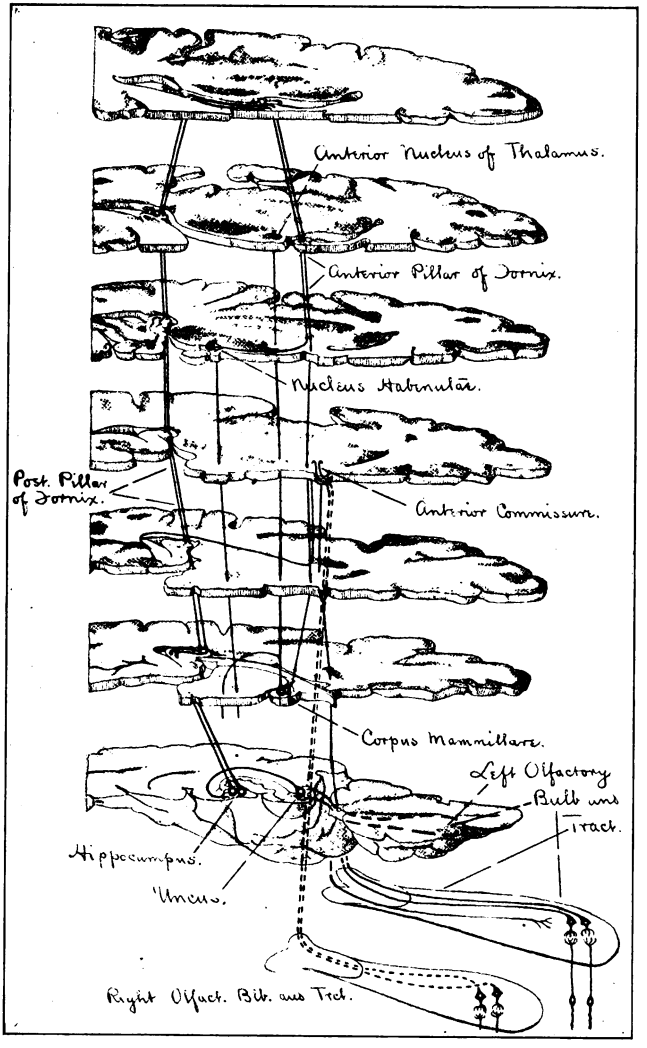


Fig. 20.—Olfactory connections.

either directly or indirectly, exerts an influence over the motor neurones of the cord, for its removal results in marked interference with the coordination of movements and the maintenance of equilibrium. Another set of fibers descends from the **red nucleus** into the opposite half of the spinal cord, and is found just medial to the direct cerebellar tract. Two descending tracts, with the course and function of which we are better acquainted, are the direct and crossed pyramidal tracts. It is perhaps better to call them the **ventral** and **lateral pyramidal tracts** (Fig. 12). They originate chiefly from cells which are situated in what are known as the **motor areas of the cortex.**

It has been found that the stimulation of certain areas of the cortex cerebri results in the contraction of certain groups of muscles. Figure 22 shows the distribution of these areas.

In these areas are large pyramidal cells,—so called on account of their shape,—whose axons pass through the corona radiata to the internal capsule, of which they form the knee and anterior two-thirds of the posterior limb (Fig. 23). The arrangement of the pyramidal fibers in the internal capsule shows a certain correspondence to that of the motor areas from which they originate; most anteriorly are situated the fibers from the motor area for the eyes, then come those for the head, and these are followed in order by those for the tongue and mouth, shoulder, elbow, wrist, fingers, trunk, hip, knee, toes. The arrangement of these fibers in definite groups according to their origin persists throughout their course, though even in the internal capsule there is some admixture. The pyramidal fibers pass down through the middle portion of the crusta of the cerebral peduncle, and through the ventral portion of the pons, into the medulla, where they form the

pyramid from which their name is derived. At the lower end of the medulla the majority of the fibers cross, in the **pyramidal decussation**, into the **lateral pyramidal tract** on the opposite side, and, descending the cord, end at successive levels in the gray matter near Clarke's column. The stimulation of the motor cells of the anterior horn must therefore entail the mediation of an intervening neurone, which perhaps stimulates several motor cells. Not all the pyramidal fibers decussate in the medulla; a few pass into the lateral pyramidal tract of the same side, some descend in the homonymous **ventral pyramidal tract.** The fibers of the ventral pyramidal tract decussate at various levels of the cord and end in the gray matter of the opposite half. The fibers which, without crossing, descend the lateral pyramidal tract end in the gray matter on the same side of the cord. By far the majority of the pyramidal fibers, then, cross in the medulla; of the remainder, the majority cross before they end; only a few end without crossing the median line. Each half of the brain controls muscles on the opposite side of the body. As the pyramidal tracts descend the cord they gradually diminish in bulk, for fibers leave them at each succeeding level to end in the gray matter. The ventral pyramidal tract disappears before reaching the lumbar region.

It is important to note that movement is not the only result of stimulating a given cortical area. If carefully localized stimulation be applied to the motor area for one set of muscles, the antagonists of this set relax; for example, stimulation of an area of flexion causes contraction of the flexor muscles concerned and simultaneous relaxation of the extensors which are antagonistic to them. The cortex can therefore both provoke and inhibit muscular contraction. Evidence of

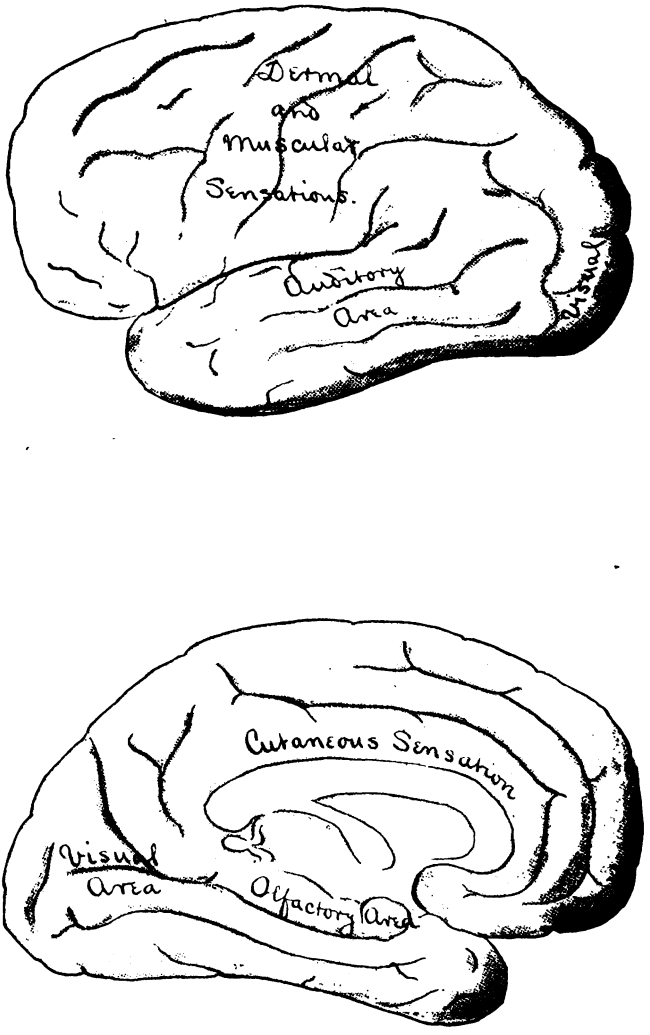


Fig. 21.—Sensory areas of the cortex cerebri.

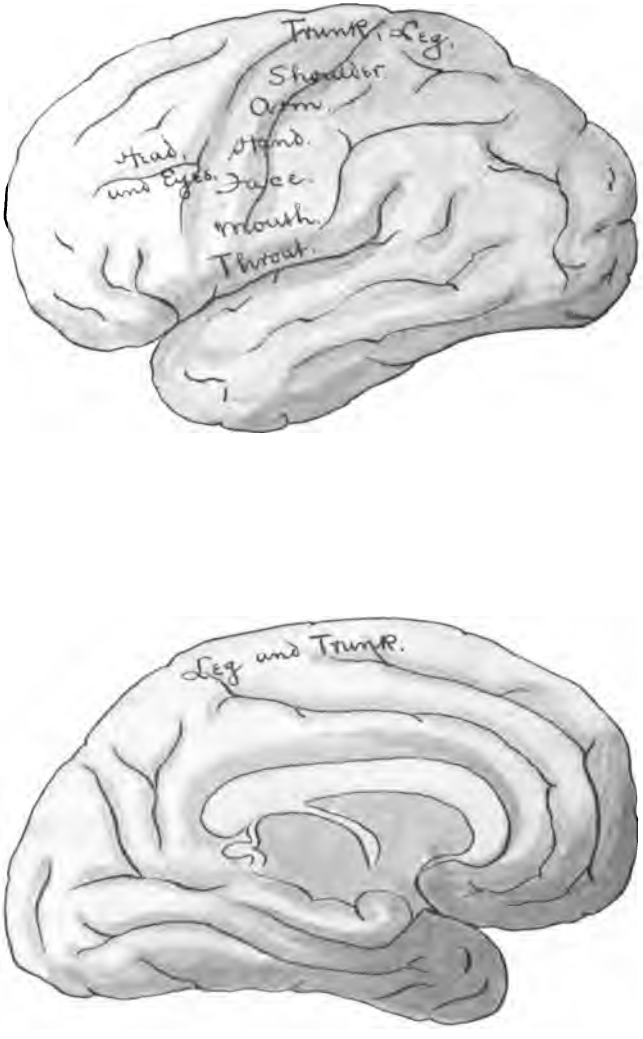


Fig. 22.—Motor areas of the cortex cerebri.

the removal of this **cortical inhibition** is seen on division of the pyramids : the spinal centers, released from control, respond more readily than usual to the afferent impulses which reach them from the periphery, and reflex muscular tone is exaggerated.

Some of the motor fibers of the internal capsule, which, on reaching the cerebral peduncle, lie medial to the fibers of the pyramidal tract, end in the motor nuclei of the cranial nerves; as is shown in figures 24 and 25. In addition, it appears that fibers descend through the median fillet, to end in the nuclei of the seventh and twelfth nerves.

Motor Cranial Nerves.—The **third cranial nerve,** oculomotor, arises from a nucleus which consists of several cell-groups situated in the floor of the Sylvian aqueduct, at the level of the superior corpora quadrigemina. The most anteriorly situated cells of this nucleus appear to be concerned in **accommodation;** the next, in **constriction of the pupil;** those innervating the **muscles of the eyeball**—namely, the inferior, superior, and internal recti, and the inferior oblique muscles—and the **levator palpebræ** being situated more posteriorly. Some axons of the third nerve decussate before their exit, but the majority do not (Fig. 24).

The **fourth cranial nerve,** or trochlear nerve, arises from a group of nerve-cells which occupy much the same position as the nucleus of the third nerve, but are situated rather more posteriorly. The axons of these cells descend for a short distance before entering the velum, in which they cross to the opposite side, and emerge as the fourth nerve. This nerve innervates the **superior oblique muscle** of the eyeball (Fig. 24).

The smaller root of the **fifth cranial nerve** arises from two nuclei, the chief of which is situated in the

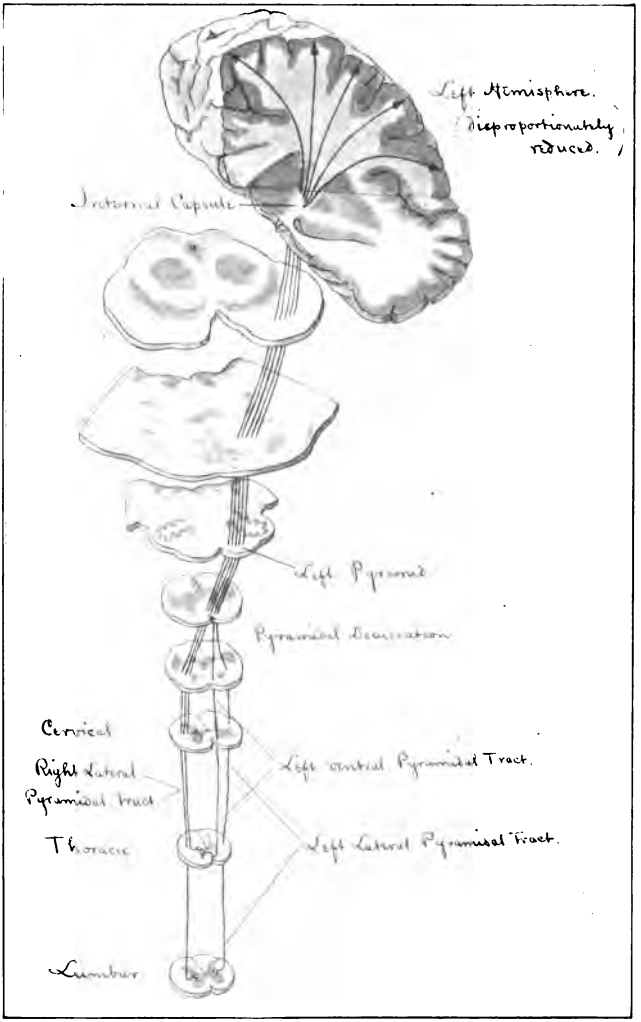


Fig. 23.—Origin and course of the ventral and lateral pyramidal tracts.

dorsal portion of the pons; the other nucleus, that of the descending root, consists of a group of cells which are scattered over a narrow area, from the chief nucleus, forward, to the level of the corpora quadrigemina. The axons of these cells join the lower branch of the trigeminus, and innervate the **muscles of mastication.** Cortical fibers, chiefly from the opposite hemisphere, probably reach the motor nucleus of the fifth nerve (Fig. 24).

The fibers of the **sixth cranial nerve,** or abducens, arise from a nucleus which is situated in the dorsomedial portion of the pons in the floor of the fourth ventricle. This nerve innervates the **external rectus** muscle of the eyeball. Cortical fibers reach this nucleus, chiefly from the opposite hemisphere (Fig. 24). This nucleus is brought under the influence of the superior corpus quadrigeminum through the posterior longitudinal bundle (Fig. 19). The same is true of the nucleus of the third nerve.

The **seventh cranial,** or facial nerve, arises from a nucleus situated ventrolaterally from that of the sixth nerve, and extending further posteriorly. The axons pass dorsomedially, and run for a short distance anteriorly beneath the floor of the fourth ventricle; they arch over the nucleus of the sixth nerve, and emerge ventrally from the lower border of the pons. This nerve is distributed to the **muscles of the face.** Cortical fibers, chiefly from the opposite side, reach this nucleus; descending fibers of the median fillet also probably reach it (Fig. 24).

The motor fibers of the **ninth cranial,** or glossopharyngeal nerve, originate from the nucleus ambiguus, which lies in the reticular formation dorsal to the inferior olive. Its axons proceed dorsomedially, turn, and emerge in company with the afferent fibers of the

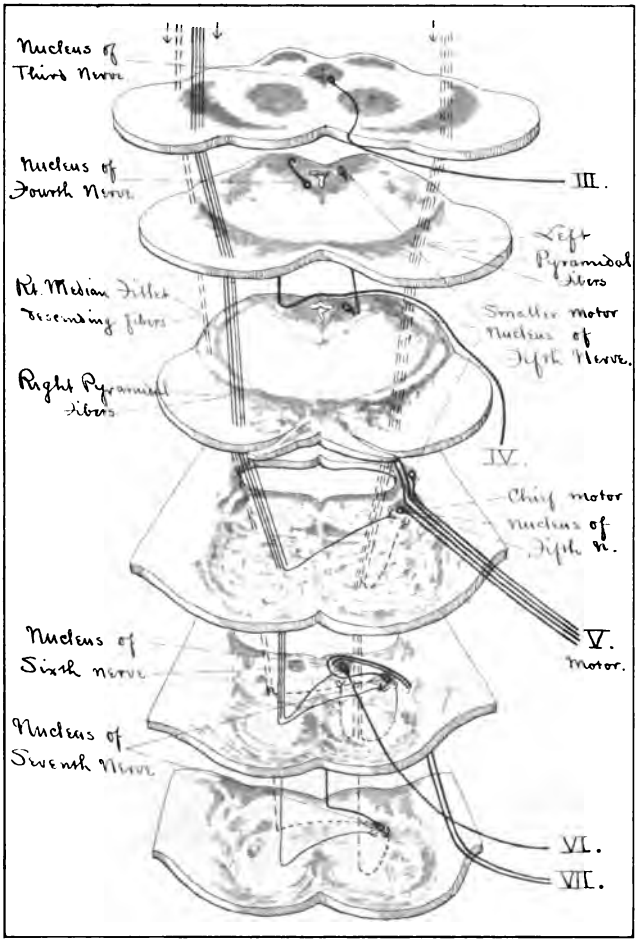


Fig. 24.—The efferent fibers of the third, fourth, fifth, sixth, and seventh cranial nerves.

nerve. The motor fibers of this nerve are distributed to the middle constrictor muscle of the pharynx, and to the stylopharyngeus. This nucleus probably receives cortical fibers, mainly from the opposite side (Fig. 25).

The motor fibers of the **tenth cranial nerve**, vagus, or pneumogastric, also arise from the nucleus ambiguus, and its central connections are the same (Fig. 25). Its motor fibers are distributed to pharynx and esophagus, larynx, bronchial muscles, stomach, and intestines. It also contains cardio-inhibitory fibers, and secretory fibers for the gastric glands and pancreas.

It is doubtful whether the cranial portion of the **eleventh nerve**, which also originates from the nucleus ambiguus, belongs in reality to this nerve or to the vagus, which it joins. The spinal portion originates from cells situated in the lateral horn of the cervical region, from the level of the first to the fifth or sixth cervical nerve. The spinal portion innervates the sternocleidomastoid and trapezius muscles. The nuclei of this nerve receive fibers from the opposite half of the brain, and possibly a few from the same side (Fig. 25).

The **twelfth cranial**, or hypoglossal nerve, is the motor nerve for the tongue, and arises from a nucleus which lies close to the median line in the dorsal part of the medulla; the upper end of this group of nerve-cells is just beneath the floor of the fourth ventricle; lower down, it is ventral to the central canal. It receives fibers from the cortex cerebri, chiefly from the opposite side, and some descending fibers from the median fillet (Fig. 25).

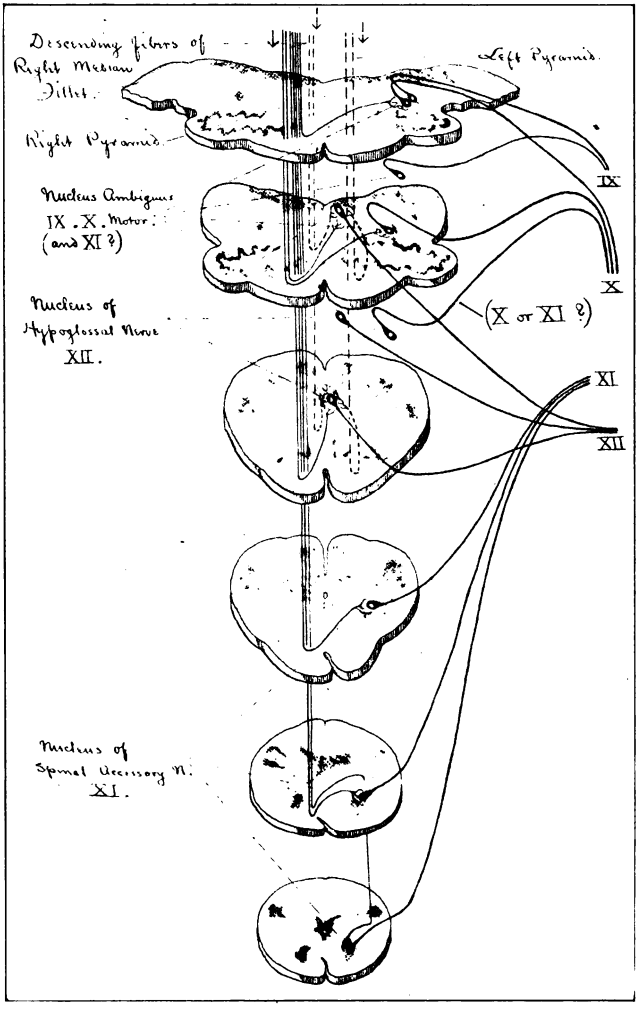


Fig. 25.—The efferent fibers of the ninth, tenth, eleventh, and twelfth cranial nerves.

THE CEREBRUM.

The cerebral hemispheres are concerned in sensation, consciousness, memory, intelligence, and volition. The destruction of a sensory area leads to loss of the sensation with which the area had to do; for instance, removal of the two occipital lobes results in complete blindness, though the eyes are uninjured. The pupils, however, continue to contract when light falls on either retina; the reflex arc concerned includes the rod and cone cells and the bipolar cells of the retina, the retinal ganglion cells and their axons, neurones of the anterior corpus quadrigeminum, and those of the third nerve which innervate the constrictor pupillæ. An injury to either of the links in this chain will, of course, put an end to the light-reflex.

Destruction of a **motor area** results in paralysis of the muscles which were innervated by this portion of the cortex. There may, in time, be some recovery of movement, especially in young patients, but the finer movements, such as those of the hand, are permanently lost. The paralyzed muscles may be caused to contract reflexly. Destruction of a **sensory area**—*e. g.*, the visual cortex—causes no motor paralysis; in the normal condition, however, stimulation of the visual area causes movements of the eyes. The visual area is, nevertheless, not classed as a motor area, for it is evident that the influence exerted over the peripheral motor neurone is not a direct one.

The result of a complete **removal of the cerebral hemispheres**, which in some of the lower animals is possible, varies. The frog, deprived of its hemispheres, can, by its appearance, hardly be distinguished from a normal frog. It is capable of maintaining its equilibrium, of leaping and swimming, but shows not the

slightest sign of memory or volition, and, save in response to some stimulus, never moves.

Pigeons bear the operation well, and their subsequent condition is similar to that of the frog. Undisturbed, they sleep most of the time; but if wakened, may walk about, clean their feathers, and if thrown into the air, fly. They must, however, be fed, for, lacking volition, they would otherwise starve to death. In time both the frog and the pigeon may begin to exhibit complicated reflexes that give the impression of intelligence.

In dogs the cortex can be completely removed only by successive operations. If this be accomplished and the animal be kept alive, it shows entire loss of intelligence and of memory, but is able to walk, and exhibits signs of sensation and emotion; the latter phenomena do not prove that the dog is conscious; they may be the expression of complicated reflex response to stimuli which are unperceived by the animal.

In man the extensive destruction of the cerebral cortex by accident or disease is usually followed by death; but small areas are often rendered functionless in this way, with the production of characteristic symptoms. The destruction of the motor areas on one side, as has been stated, results in paralysis of the corresponding muscles on the opposite side of the body; this may be accompanied by no loss of sensation. Destruction of the internal capsule, on the other hand, if it be complete, causes both motor and sensory paralysis of the opposite half of the body. The well-being of the motor neurones concerned in voluntary movements is not all that is necessary to the proper use of our muscles. Movements in which but one muscle is brought into play are exceptional; as a rule, we use a group, or several groups, of muscles at one time, and the successful accomplishment of the movement is only possible if the

contraction of the different members of the group be co-ordinated by the nervous system. **Coordination** is largely dependent on the reception of afferent impulses from the muscles themselves, and is consequently rendered imperfect by a break in the afferent pathway. Such is the case in tabes, in which the dorsal columns of the spinal cord are affected, and, consequently, **muscle-sense** is defective. In the lower animals the division of all the dorsal nerve-roots which innervate a limb, leads to complete disuse of this member (apesthesia), though the motor pathway is in no way injured by the operation, and the muscles can be caused to contract by artificial stimulation of the motor cortical area.

If figures 21 and 22 be examined together, it will be seen that by no means the whole of the cortex has been mapped out into motor and sensory areas; large cortical fields intervene, the stimulation of which leads to no visible result. These have been called by Flechsig **association areas**, and are perhaps concerned with the interpretation of sensations, in memory, and with intellectual processes in general. There are several areas in the cortex of the left hemisphere which are intimately connected with the understanding and use of language. A lesion strictly confined to the left auditory area, though it causes deafness on the right side, may not interfere with the understanding of spoken language or with speech; but if the lesion is more wide-spread and includes the neighboring cortical area, the patient no longer understands the words which he can hear perfectly well with the left ear. The result seems to be due to an injury to an association area, rather than to the auditory area itself. The condition is one of **sensory aphasia**. Disease of part of the left occipital lobe leads to sensory aphasia of a different form, or **alexia**; in this,

the defect consists in the failure to understand written language; speech and the understanding of spoken language being retained. The posterior part of the left inferior frontal gyrus, Broca's area, is known as the **speech center.** Disease of this part of the cortex results in loss of speech, while spoken and written language are still understood; this is known as **motor aphasia.** The condition is not due to a paralysis of the muscles of phonation, though the area corresponds in part to the motor area for the tongue, larynx, etc. The patient can still use these muscles, and may, under the influence of emotion, speak in a rational manner; sometimes the power of singing is retained. It is possible, more especially in young patients, to regain the power of speech, through the education of the corresponding center on the right side. The right speech center may perhaps be used to a certain extent by the normal individual, and this may account for the retention of emotional speech by the aphasic. Left-handed individuals, whose peculiarity perhaps depends on anatomic superiority, in their case, of the right hemisphere over the left, use the right speech center.

Not only are neighboring convolutions connected with one another by means of **association fibers,** but the different lobes of each hemisphere are connected in the same way; in addition, the two hemispheres are united by association fibers, through, for example, the corpus callosum. Stimulation of the corpus callosum causes, through indirect excitation of the cortical motor areas, bilateral movements.

The Cerebellum.—The voluntary control of movements, and more especially of those concerned in progression and in the maintenance of equilibrium, is very much interfered with by injury to the cerebellum. As we have seen, afferent impulses reach the cerebellum through the

dorsal, direct cerebellar, and ascending anterolateral tracts of the spinal cord, and through the vestibular nerves from the semicircular canals; it also receives fibers from the inferior olives. It is, then, an important station for the reception of afferent impulses from a wide peripheral area. Nevertheless its destruction does not result in loss of sensation; the impulses which reach the cerebellum seem rather to be concerned in unconscious reflex coordination of muscular movement. The patient who suffers from cerebellar disease, and, consequently, from incoordination of movement, is perfectly aware, even when his eyes are closed, that his motions are ill directed, but lacks the power to order them rightly. With continued practice the defect may, to a certain extent, be overcome; but it would be quite impossible for such an individual to run downstairs; careful attention must be directed to each movement if it is to be carried out correctly. Although the cerebellum is connected with the motor cells of the spinal cord by descending fibers, its influence on coordination seems rather to be exerted through fibers which ascend toward the cerebrum, and end either in the thalamus or in the cortex. The **vermis** is the portion of the cerebellum which is concerned in maintaining equilibrium; the function of the large lateral lobes is unknown. The fibers which pass from the cerebellum to the cerebrum cross the median line in the superior peduncles, and end on the opposite side in the red nucleus or optic thalamus; from these bodies impulses are carried to the cortex by another set of neurones. Impulses pass in the opposite direction, from the cerebrum to the cerebellum, over fibers which connect the frontal and temporal cortex with the gray matter of the pons, and the gray matter of the pons with the opposite half of the cerebellum. The lateral vestibular nucleus, or Deiters' nucleus, probably acts as

a relay station for the forwarding of impulses from the cerebellum to the gray matter of the spinal cord on the same side of the median line. The motor symptoms which follow injury to one half of the cerebellum appear on the side of the lesion; this is to be expected, since the fibers which leave the cerebellum transmit impulses, on the one hand, to the same side of the cord, on the other, to the opposite cerebral hemisphere; and, as we know, the cerebral control of a muscle is exercised by the opposite half of the brain.

The Semicircular Canals.—The afferent impulses which pass from the semicircular canals to the central nervous system are of the utmost importance in the conscious appreciation of the movements of the body as a whole, and of its position, and in the reflex and voluntary maintenance of equilibrium. The nerve-fibers which enter the medulla through the vestibular nerve are the central axons of the bipolar vestibular ganglion cells; the peripheral axons (or dendrites?) of these cells are distributed to the macula acustica of the utricle, and to the cristæ ampullares of the semicircular canals. In these structures the fibers branch, their terminal fibrillæ surrounding the bodies of the hair-cells. The hair-cells are so called on account of the hair-like processes which project from their free surface into the endolymph which fills the membranous labyrinth. The semicircular canals on each side are arranged in the three planes of space, at right angles with one another; consequently, the head cannot be moved without causing, in one or other of the canals, a change in the pressure which is exerted by the endolymph on the hair processes of the epithelium. Further, the relations existing between the arrangement of the canals on the two sides of the head is such that a change of pressure on the hair processes in one ampulla is accom-

panied by a change of pressure in the opposite direction in the ampulla of the parallel canal on the opposite side. Changes of pressure on the hair-cells cause stimulation of the terminations of the vestibular nerve-fibers, and these transmit impulses to the medulla. The central connections of these fibers have been discussed. Disease of or injury to any of the semicircular canals may cause **vertigo**; but if all the canals on one side are removed, there will be marked loss of equilibrium and muscular coördination, resulting in a falling to the affected side ; a result which is especially noticeable in birds, which show a very perfect development of the sense of equilibration.

QUESTIONS FOR CHAPTER IX.

Compare the path followed by a motor-nerve impulse passing to a skeletal muscle with that of an impulse which reaches involuntary muscle?

How may we determine whether the ventral nerve-roots contain nerve-fibers which have descended the cord from a higher level?

How may we ascertain whether paralysis of a muscle depends upon injury to pyramidal fibers or to ventral root-fibers?

In what different ways may a nerve-center be directly influenced?

Injury to what different structures causes a loss of reflex contraction of muscle?

On stimulation of a motor cortical area, how many neurones are concerned in the transmission of the motor impulse to a muscle-fiber?

Having divided a nerve-trunk, what must be done to prevent permanent paralysis of the muscles innervated by this nerve?

How can you tell when a divided nerve has renewed its connection with a muscle?

Would you expect the paralysis which results from destruction of the gray matter of the cord to be permanent or otherwise?

To what extent is the voluntary use of muscles affected by division of the posterior nerve-roots?

How can we decide, by the examination of a section of the upper cervical cord, whether degeneration found in the dorsal column was the result of a lesion situated in the lower cervical or lower thoracic region?

Given three animals, A, B, and C: the left internal capsule of A having been destroyed, the left half of the spinal cord of B having been transversely divided in the thoracic region, and in C all the lumbar and sacral posterior nerve-roots having been divided, explain the effect in each case, if any exist, on the voluntary movements of the left leg, and on the left knee-jerk?

How can we ascertain, from the nature and distribution of sensory paralysis, whether the causative lesion is situated in the internal capsule, or consists in hemisection of the cord?

What lesion will bring about loss of voluntary movement of the leg, and exaggeration of the knee-jerk?

What lesion will cause incoordination of voluntary movement and loss of the knee-jerk?

How can we determine the level of a lesion of the cord which has brought about paralysis of the leg?

Will a lesion of the cord which causes paralysis of the legs necessarily result in paralysis of their arterioles?

How do the results of injury to the ventral nerve-roots differ, with regard to muscular contraction, from those arising from injury to the dorsal nerve-roots?

Where do peripheral sensory nerve-fibers originate?

In respect to voluntary contraction, reflex contraction, and sensation, how do the effects of the following lesions differ: Destruction of the motor cortical area on one side; destruction of the internal capsule on one side; division of the pyramid of the medulla; and hemisection of the cord in the lower cervical region?

What comment have you to make on a case in which loss of speech accompanied paralysis on the left side of the body?

How may an animal be blinded without destroying visual reflexes?

What lesions will lead to a loss of the pupil light-reflex without causing blindness?

What is the result of injury to or removal of the semicircular canals?

CHAPTER X.

THE SPECIAL SENSES.

VISION.

WHEN light passes from one medium into another the density of which differs from that of the first, the course of those rays which do not fall perpendicularly upon the surface of the second medium is changed—the rays are refracted. As light enters the eye, it passes from the air into the cornea, then into the aqueous humor, then into the lens, and, traversing the vitreous humor, reaches the retina. It thus passes through four refracting surfaces on its way to the retina—namely, the anterior and posterior surfaces of the cornea, which are parallel to one another; and the anterior and posterior surfaces of the lens, which are parallel neither to the corneal surfaces nor to each other. The centers of curvature of all these surfaces are, however, situated approximately upon one axis, so that a ray of light traveling along this axis will suffer no refraction on its way to the retina. Other rays which enter the eye will be refracted at each of the four surfaces which they traverse. The extent of refraction depends upon the course of the ray, the curvature of the surface, and the difference in the density of the two media separated by the surface. The more obliquely a ray of light cuts the refracting surface, the greater the curvature of the surface, and the wider the difference between the density of the media, the greater will be the degree of refraction. Consider-

able refraction occurs at the anterior surface of the cornea, where the light passes from the air, the refractive index of which is 1.0, into the cornea, the refractive index of which is 1.37, its radius of curvature being 7.8 mm. Very little refraction occurs at the posterior surface of the cornea, since the refractive index of the aqueous humor (1.33) differs but little from that of the cornea. The refractive index of the lens is 1.43, the radius of curvature of its anterior surface being, when the ciliary muscle is at rest, 10 mm.; here, again, the refraction is considerable. The rays are again refracted at the posterior surface of the lens, the radius of curvature of this surface being 6 mm.; here the rays pass into the vitreous humor, the refractive index of which is the same as that of the aqueous humor (1.33).

This complex system of media and refracting surfaces may, however, be represented by what is known as the **reduced eye**, which consists of one medium with an index of refraction about the same as that of the aqueous and vitreous humors, bounded by one surface with a radius of curvature of 5.1 mm. The refraction suffered by a ray of light on entering such an eye, would be equal to the total refraction suffered, on its way to the retina, by a ray forming the same angle with the principal axis of the normal eye. This imaginary refracting surface lies between the cornea and the lens. The nodal point of the reduced eye—that is, the center of curvature of its refracting surface—is situated 0.47 mm. in front of the posterior surface of the lens, and, of course, on the principal axis. Such a reduced eye represents the normal eye only when the ciliary muscle is at rest. The refracting surface of a reduced eye that shall accurately represent the refraction that occurs in the normal eye when the ciliary muscle is contracted must have a greater curvature. Rays of light the

course of which is parallel to the principal axis are refracted to meet, at the posterior principal focus, on the principal axis; when the ciliary muscle is at rest, the posterior principal focus falls upon the retina. The anterior principal focus lies 12.9 mm. in front of the cornea, on the principal axis; rays which emanate from this point are, within the eye, rendered parallel to the principal axis. The cardinal points of the system are the anterior and posterior principal foci, the nodal point, and the principal point, the latter being the point where the optic axis cuts the refracting surface of the reduced eye, and being situated in the aqueous humor 2.2 mm. behind the anterior surface of the cornea.

Rays of light which fall perpendicularly upon the refracting surface of the reduced eye suffer no refraction, but pass on through the nodal point to the retina. Consequently, a ray of light emanating from a point above the principal axis, and falling perpendicular to the refracting surface, will reach the retina at a point below the principal axis; a ray coming from a point situated below the principal axis will strike the retina above it. Light stimulates certain structures in the retina, and, as a result, nerve impulses are transmitted to the brain, there giving rise to sensations. By experience we learn to associate sensations resulting from stimulation of the lower part of the retina with light emanating from a point situated above the optic axis; sensations resulting from stimulation of the upper part of the retina, with light coming from a source situated below the optic axis; the same is true of stimulation of the lateral portions of the retina—the resulting sensations are associated with points on the opposite side of the axis.

The formation of an image on the retina is shown in figure 26. With the exception of the principal ray,

which falls perpendicularly upon the refracting surface of the reduced eye (this surface is represented in the figure by a broken line), the diverging rays which are reflected from a given point of the surface of an opaque object, and which enter the eye, are refracted to meet the principal ray upon the retina, and form here an image of the point from which they were reflected. In like manner, there are formed images of other equidistant points of the object at the points where their principal rays strike the retina. In this way an image of

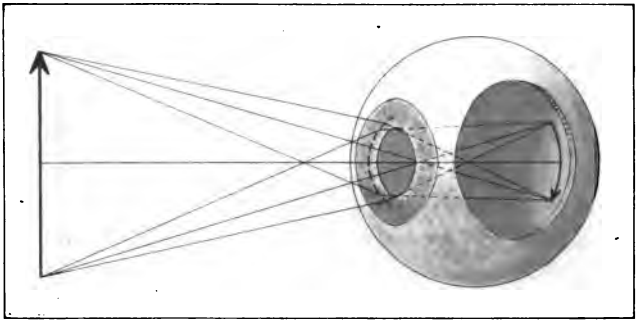


Fig. 26.—Formation of an image on the retina.

the whole object may be formed; it is, of course, inverted.

When the ciliary muscle of the eye is at rest, rays of light which diverge from a point near the eye are not, by the time they reach the retina, brought to a focus; consequently, they form, instead of a sharp image, a diffusion circle. In order that a sharp image of a near object may be formed on the retina, the focal distance of the eye must be shortened. This is known as **accommodation**, and is accomplished by the contrac-

tion of the **ciliary muscle.** When this muscle is at rest, the lens is flattened by the tension to which the suspensory ligament and capsule are subjected owing to intraocular pressure. When the ciliary muscle contracts, it stretches the elastic choroid coat, and pulls forward its anterior margin, to which is attached the suspensory ligament. The suspensory ligament and capsule being thus slackened, and the pressure on the inclosed lens being reduced, the anterior surface of the elastic lens bulges forward, its curvature is increased, and, with the curvature, the power of refraction. The image of an object which is near the eye may thus be formed upon the retina. The normal eye cannot, however, be accommodated for objects which lie within 10 or 12 centimeters of the cornea. This is known as the near-point of distinct vision. Since parallel rays are brought to a focus upon the retina of the resting eye, the far-point of vision is at an infinite distance.

Accommodation is accompanied by **constriction of the pupil,** and by **convergence** of the optic axes of the two eyes; to a certain extent the latter may, by practice, be dissociated from the two former. The motor impulses concerned in causing these events reach the eye through the **third nerve**; pre-ganglionic fibers which carry motor impulses to the ciliary muscle and constrictor pupillæ end in the ciliary ganglion, and make connection here with cells whose post-ganglionic fibers are distributed to these structures. Although the ciliary muscle is of the unstriped variety, it is under the control of the will, and the eye may, by practice, be accommodated for short distances without fixing the attention upon near objects. No direct voluntary control can be exercised over the size of the pupil, but it may be indirectly varied through voluntary contraction or relaxation of the ciliary muscle, with which its

movements are associated. Light, when it falls on either retina, causes reflex constriction of both pupils; the afferent impulses concerned being probably carried to the anterior corpus quadrigeminum, whence impulses are dispatched to the nuclei of the third cranial nerves. The size of the pupil is also influenced by **pupillo-dilator fibers,** which leave the spinal cord in the second thoracic nerve and enter the sympathetic chain to end in the superior cervical sympathetic ganglion. Connection is here made with nerve-cells whose axons form post-ganglionic fibers that pass through the cavernous plexus to the Gasserian ganglion, and thence with the ophthalmic division of the fifth nerve to the eye, reaching the latter through the long ciliary nerves. The pupillo-dilator center is probably situated in close proximity to the nucleus of the third nerve, and appears to exert a tonic influence, for division of the cervical sympathetic is followed by constriction of the pupil. Dilatation of the pupil accompanies relaxation of the ciliary muscle; it may be caused reflexly by stimulation of afferent nerves, as, for instance, by tickling the palm of the hand, or by applying a painful stimulus to the back of the neck; it is influenced by the emotions. It is probable that dilatation depends upon contraction of radially disposed cells of the iris, but whether or no these cells are plain muscle-cells, is uncertain. Both accommodation and the size of the pupil are affected by certain drugs; atropin, for example, paralyzes the terminations of the motor nerve-fibers of the ciliary and constrictor muscles, and probably stimulates the fibers which cause dilatation; physostigmin, on the other hand, stimulates the terminations of these nerves, and paralyzes the dilators.

Myopia, or short sight, depends upon the fact that the posterior principal focus falls in front of, instead of

upon, the retina. In the **hypermetropic,** or long-sighted eye, the posterior principal focus lies behind the retina. The former condition usually results from the anteroposterior diameter of the eye being abnormally great; the most frequent cause of hypermetropia is an abnormally small anteroposterior diameter of the eyeball. The hypermetropic eye has, when the ciliary muscle is at rest, neither near- nor far-point of distinct vision, for rays which come from even an infinite distance are not brought to a focus by the time they reach the retina, and still more is this the case with those emanating from objects which are near the eye; the condition may, however, be compensated to a certain extent by accommodation, but the near-point of vision is always further from the eye than the normal. The near-point of distinct vision of the myopic eye is nearer to the eye than that of the **emmetropic** or normal eye, consequently a larger image of a small object may be formed on the retina of a myopic eye, and small objects may thus be seen more distinctly by a short-sighted individual than by one whose vision is normal. The far-point of distinct vision of the myopic eye is at a comparatively short distance, for only the divergent rays which fall upon the cornea can be focused upon the retina; parallel rays are brought to a focus before reaching it. As age advances, the power of accommodation is impaired, through weakness of the ciliary muscle and lessening of the elasticity of the lens, the condition being known as **presbyopia;** the near-point of distinct vision gradually recedes from the eye, but there is no interference with the vision of distant objects.

Astigmatism is an irregularity of vision which is usually dependent on differences in the curvature of the cornea. In the commonest form the curvature of the cornea is greater in the vertical than in the horizontal mer-

idian, and, as a result of this, the rays which, diverging from a given point, fall upon the vertical meridian of the cornea, are brought to a focus earlier than those which fall upon the horizontal meridian. Consequently, when the eye is so accommodated that the anterior of these two foci falls upon the retina, the image formed will be, instead of a point, a horizontal line; if the posterior focus falls upon the retina, the image will be a vertical line (Fig. 27). Almost every eye is more or less astigmatic, and none are free from defects. One constant defect consists in **spheric aberration**, which depends upon the fact that rays falling upon the periph-

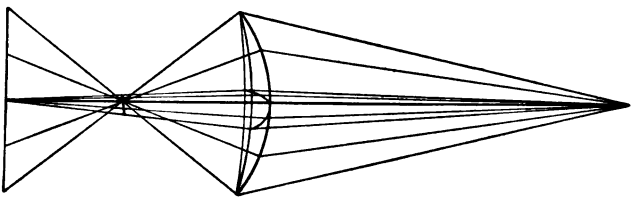


Fig. 27.—Illustrating astigmatism.

ery of the lens are more refracted, and brought to a focus earlier, than those which fall nearer to the principal point. This effect is, however, to a certain extent, neutralized by the curvature and index of refraction of the peripheral portion being less than is the case with the more central portion of the lens. The iris, too, forms a diaphragm which prevents light from falling on the periphery of the lens, and this is of special importance in the case of the more divergent rays which reach the eye from near objects; as we have seen, the iris contracts when near objects are viewed. **Chromatic aberration** is caused by dispersion due to the unequal refrangibility of rays of different wave-length; those of

shorter wave-length, *e. g.*, the violet rays, are more refracted than those of greater wave-length, *e. g.*, the red rays. Under ordinary circumstances, neither spheric nor chromatic aberration interferes with distinct vision.

Color Vision.—White light on analysis is found to consist of a mixture of rays of varying wave-length. When light falls upon the retina, the resulting sensation varies with the wave-length of its component rays. According to the Young-Helmholtz theory, there are in the retina three substances, all of which are to a certain extent acted upon by any ray of light, whatever its wave-length; but the readiness with which each substance reacts to different rays varies. For instance, rays the wave-length of which is in the neighborhood of 0.000675 mm. affect one substance more than the other two, and give rise to a sensation of red; rays of about 0.000525 mm. wave-length produce the greatest effect on the second substance, and give rise to a sensation of green; rays of 0.000430 mm. wave-length cause the greatest change in the third substance, and result in a sensation of violet. A sensation of yellow results from the simultaneous production of red and green sensations in certain proportion; a sensation of orange is produced by slightly increasing the red sensation and lessening the green. Thus a host of different color sensations may be produced by the fusion of the primary sensations in varying proportions. The sensation of white results from the fusion of all three primary sensations in definite proportions; this is what occurs when ordinary daylight falls upon the retina, but to produce this result it is not necessary that all the rays of the visible spectrum should enter the eye. Any two rays which between them excite all three color sensations in the right proportion, will give rise to a sensation of white; for instance, a ray of the wave-length 0.000564 mm.,

when it alone reaches the retina, causes a sensation of greenish-yellow by acting about equally on the visual substances concerned in red and green sensations; if to this ray be added one of the wave-length 0.000433 mm. which by itself causes a sensation of violet by acting to about the same extent on the third substance, a sensation of white will result. Every ray situated toward one end of the spectrum has its complementary ray, found toward the opposite end, combination with which gives rise to a sensation of white. Rays near the middle of the spectrum which give rise to a sensation of green require to be combined with rays from both ends of the spectrum in order to cause a sensation of white. A sensation of black is caused by the absence of any stimulus. There are certain facts in color vision which cannot be satisfactorily explained on this theory, and in consequence several others have been advanced; to all these there are, however, objections. According to the theory of Hering, there are six primary color sensations, depending on anabolic or katabolic changes in three visual substances. In one of these substances katabolic changes may be excited by the rays of any part of the visible spectrum, and a sensation of white results; in the absence of light, anabolic changes predominate, and give rise to a sensation of blackness. Another substance is caused to break down by the rays of greater wave-length, giving rise to a sensation of red, while it is rapidly built up under the influence of the rays of medium length, with a resulting sensation of green. The third substance suffers katabolic changes under the influence of rays which thus produce sensations of yellow, and undergoes constructive changes when exposed to the rays of shorter wave-length which thus produce a sensation of blue. When rays of all wave-lengths fall upon the retina, the metabolism of only the

"white-black" substance is affected; the other two substances remain in equilibrium. Orange sensations result from the simultaneous break-down of the red-green and yellow-blue substances, violet sensations from the simultaneous building up of yellow-blue and break-down of red-green substance.

Color-blindness appears to depend upon the existence in the retina of the individual of but two visual substances. As a rule, those who are color-blind fail to distinguish between red and green; this may be explained on the Young-Helmholtz theory, by supposing either the "red substance" or the "green substance" to be absent from the retina; on Hering's theory by the absence of the "red-green substance."

When light falls upon the retina, it affects both the pigment epithelial cells of the outer layer, and the rods and cones; visual sensation depends upon stimulation of the latter elements, and it results whatever be the nature of the stimulus. Pressure when applied to the eyeball affords mechanical stimulation of the retina, and a visual sensation follows. If in the dark sudden pressure be applied to the nasal side of the eyeball, the resulting sensation resembles that produced by a flash of light occurring on the opposite side of the visual axis, and to the subject it appears to be the consequence of such an event taking place outside the body. If the experiment is made in the light, the impression of a dim blue disc is given. The retina may also be stimulated electrically, with the production of visual sensations.

Different parts of the retina are not equally sensitive to light, and a variation in the quality of light affects them differently. We can most accurately distinguish between closely adjacent points when their images fall upon the yellow spot, or **macula lutea**; in this respect acuteness of vision gradually diminishes as the

periphery of the retina is approached. The same is true in respect to color vision; the extreme periphery of the retina is color-blind. On the other hand, the macula lutea is not the part of the retina that is most sensitive to dim illumination. Rods are absent from the macula lutea, cones only being present; as the periphery is approached, the number of rods increases, the number of cones diminishes, and before the border is reached the cones disappear. It seems probable that the cones are chiefly concerned in acute vision and in color vision, while the rods minister to the perception of luminosity without, perhaps, affording a means for the appreciation of color. The rods contain a substance, **visual purple**, which is absent from the cones, and it may be owing to the presence of this substance that the rods are most readily stimulated by rays of light of short wave-length, for it is by these that visual purple is most rapidly bleached. Visual purple is rendered colorless by exposure to light, but during the process an intermediate substance, a pigment called visual yellow, is formed. On exclusion of light, visual purple again slowly appears in the rods, but not in the absence of the layer of pigment epithelium, which evidently exerts an influence on its formation. The **optic disc**, that part of the retina where the fibers of the optic nerve leave the eye, is devoid of rods and cones, and is blind. Of this defect we are unconscious, until it is pointed out to us that, with but one eye open, the image of an object which falls upon this area is unseen. The image of an object never falls simultaneously upon the blind spots of both eyes.

When light falls upon the retina, the effect on consciousness varies with the intensity of the light, with the duration of the exposure, with the size of the retinal area illuminated, and with the condition of the retina.

The excitability of the retina is reduced by exposure to light; it becomes fatigued, and visual sensations are less intense; this probably also depends upon fatigue of the central visual mechanism. In order to excite visual sensation, light must be of certain intensity, this intensity varying with the part of the retina upon which it falls. We cannot distinguish between the different intensity of two lights, unless one be brighter than the other by one-hundredth part, and, consequently, the brighter the lights, the more difficult it is to appreciate their different value. A flash of light may appear less bright than a somewhat weaker light that lasts longer. A small light may appear less luminous than a larger one which is in reality of less intensity. Since the sensation outlasts the stimulus by a short period, a rapid succession of stimuli of very short duration gives rise to a continuous sensation. The survival of a visual sensation after the stimulus has ceased is known as a positive **after-image.** Negative after-images are fatigue phenomena; for instance, if after fixing the eye for a few moments upon a red object it is turned to a white surface, there appears a greenish image of this object; this is explained by assuming that in the area of the retina upon which the rays from the red object fell the visual substance upon which the red rays take most effect has been used up or rendered inexcitable to a greater extent than either the green or the violet perceiving elements; consequently, when the whole retina is subsequently exposed to white light, which excites all three primary sensations, the two which have not been fatigued will predominate, and we experience a sensation of greenish-blue. The color of a negative after-image is always complementary to that of its original.

When two objects the colors of which are complementary to one another are placed in contact, the color

of each, more particularly along the adjacent edges, appears to be intensified. This may be explained by assuming that stimulation of any retinal area causes simultaneous changes to occur in neighboring areas; by some, these induced changes are supposed to be similar to those occurring in the stimulated area; by others, they are considered to be of an opposite nature.

A white object on a dark field looks larger than it does on a white field; this is called **irradiation**, and depends upon the failure of the eye to bring all the rays to a proper focus, the size of the retinal image being slightly increased through the formation of diffusion circles instead of points.

To each eyeball are attached **three pairs of muscles**, the two members of each pair being antagonistic to each other. The movements of the two eyes are associated in such a way that their visual axes are kept parallel to each other when directed toward distant objects. During accommodation the visual axes converge. In what is known as the primary position of the eyes, the visual axes are parallel, and, the head being erect, are directed toward a distant point at their own level. The center of rotation of the eyeball lies 13.54 mm. behind the anterior surface of the cornea on the optic axis. The optic axis does not exactly correspond to the visual axis, but cuts the retina on the inner side of, and slightly above, the macula lutea. Rotation of the eyes from the primary position to the right is caused by contraction of the right external rectus muscle and left internal rectus; horizontal convergence is caused by contraction of the two internal recti. Upward rotation is brought about by the simultaneous contraction of the superior recti and inferior oblique muscles; downward rotation, by the simultaneous contraction of the inferior recti and superior oblique

muscles. More than two muscles must act upon each eye in order to bring about oblique upward or downward movement; this is accompanied by more or less wheel movement, or rotation on the optic axis. The voluntary contraction of one muscle is accompanied by **inhibition of its antagonist.**

As long as, through the associated movements of the two eyes, the visual axes are directed toward the same point, an image of this point will fall upon the macula lutea of each eye, and will give rise to a single sensation. The maculæ luteæ are not the only areas of the retinæ simultaneous stimulation of which gives rise to a single sensation; each retinal area, with the exception of those near the nasal edges of the retinæ, has a **corresponding area** in the opposite retina. When the two retinal images of an object fall upon corresponding or identical areas, the object appears single; when the images fall upon areas which do not correspond, the object appears to be double. Slight asymmetry in the position of images falling upon peripheral areas of the retinæ does not so readily cause diplopia (double vision) as does the asymmetric arrangement of images on the maculæ luteæ.

We first learn to interpret our visual sensations through comparison with sensations provoked through other channels. Our **visual judgment** of the size of an object is formed by comparing the sensation which it excites with those produced by other objects with which we are familiar, and if the object be large, by the angle through which the eye must be moved in order to cover its surface. The movements of the eye are estimated partly through the intensity of the effort expended in causing the contraction of the ocular muscles, and partly through the muscular sensation resulting from their contraction. The distance of an object may be much

more accurately determined by using both eyes than by using only one; in the case of a near object, the degrees of accommodation and of convergence are important aids to judgment of distance. It is difficult to form an idea of the shape of an unfamiliar solid object by means of one eye, but since, when both eyes are used, it is viewed from two points, the retinal images differ slightly, and we are enabled to appreciate its depth.

HEARING.

Sound-waves that enter the external auditory meatus cause vibration of the tympanic membrane, and are transmitted through the chain of ossicles, which vibrate as a whole, to the perilymph of the internal ear. The vibration of the perilymph is transmitted to the endolymph of the membranous labyrinth, and in some way takes effect on the terminations of the nerve-fibers of the auditory branch of the eighth cranial nerve. Pressure on the two sides of the tympanic membrane is equalized by the communication which exists between the middle ear and the pharynx by means of the Eustachian tube; uneven pressure would interfere with the vibration of the membrane.

The vibrations which give rise to a musical sound are rhythmic; a noise results from arhythmic vibrations. Sounds vary in **intensity**, or loudness, in **pitch**, and in **quality**. Intensity depends upon the amplitude of the vibration; pitch, upon the rate of vibration. A single sound emitted by a musical instrument is usually not simple, but compound, and this depends upon the admixture of overtones with the fundamental tone. The same note produced by different instruments differs in quality, owing to variation in the number and intensity of accompanying overtones. When two sounds occur

simultaneously, the vibrations upon which they depend do not reach the ear separately, but are fused, and form a compound wave; nevertheless, we are capable of analyzing a complex sound. The ear probably contains a system of resonators, which, like the strings of a harp or other instrument, are caused to vibrate when subjected to the influence of sound-waves, each resonator responding to a tone of definite pitch. The basilar membrane of the cochlea, with its thousands of radial fibers of different lengths, perhaps serves as a system of resonators in the analysis of sounds, the vibration of each fiber being communicated, through the organ of Corti, to a particular nerve-fiber of the auditory nerve.

Our aural judgments are much less exact than our visual judgments, and even by the use of both ears it is difficult to determine whence a sound reaches us. This is especially true of sounds which emanate from a point in the median vertical plane. It is less difficult to locate sounds whose source of origin is lateral to the head, for, in this case, the intensity, and perhaps the quality of the sound, as it reaches the two ears varies.

SMELL.

The true olfactory mucous membrane is very limited in extent, and is confined to that portion of the nasal mucous membrane which covers the medial surface of the superior turbinated bone, and the corresponding area of the septum. Here are situated cells which give off the fibers which constitute the olfactory nerve, and end in the olfactory bulb. The air as it is inspired does not pass over this area, but gases and particles of odorous substances which enter the nose reach the olfactory mucous membrane by diffusion. Odorous substances may excite a sensation of smell when intro-

duced into the nostrils in solution in normal saline, but not in distilled water, which probably injures the olfactory cells.

TASTE.

Not the whole of the oral mucous membrane is sensitive to sapid substances; the taste organs are confined to the back, the tip, and the edges of the tongue, and to the palate and the pillars of the fauces; their distribution, however, varies considerably in different individuals. The taste-buds, which are found on the sides of the circumvallate papillæ, and on the fungiform papillæ, are supposed to serve as end-organs of taste, but probably there are others. The back of the tongue is most sensitive to bitter substances; the tip and sides, to sweet substances. The other tastes are acid and salt; flavors are appreciated by the olfactory cells, and are not true tastes. Nerve-fibers which are concerned in taste are supplied to the back of the tongue by the glossopharyngeal nerve, and to the anterior two-thirds by the lingual, but the path by which these fibers enter the medulla is uncertain.

QUESTIONS FOR CHAPTER X.

Can parallel and divergent rays of light which happen to fall upon the eye be simultaneously focused on the retina?

During accommodation, where are parallel rays brought to a focus?

What sort of lens must be used for the correction of myopia?

What sort of lens is needed after removal of the lens from the eye?

To what extent is vision interfered with by the application of atropin?

How do we know that light does not stimulate the fibers of the optic nerve?

Why, when accommodation is relaxed, does a near object appear to be double?

Why is vision indistinct when the eye is immersed in water?

Why do hypermetropic eyes tire more readily than myopic eyes?

What effect on the eye has division of the cervical sympathetic nerve?

When the internal rectus muscle of one eye is paralyzed, the eyeball will be rotated outward, owing to the unresisted tonic contraction of the external rectus. Why, under these circumstances, should turning the opposite eye outward cause the injured eye to return to the primary position?

Why does the application of pressure to one side of the eyeball cause diplopia?

If sound-waves reach the retina, why do they not result in visual sensation?

INDEX.

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